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THE HELICOPTER ROUTE SELECTION MODEL (DYNFLITE)

Final Report

by

Gordon M. Clark
Don C. Hutcherson
David L. Bitters

August 1976

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DIRECTORATE OF COMBAT OPERATIONS ANALYSIS
U.S. Army Combined Arms Combat Developments Activity
Ft. Leavenworth, Kansas 66027

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Department of Industrial and Systems Engineering
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Columbus, Ohio 43210

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This report describes the results of research to develop a helicopter attack route selection model, called DYNFLITE, for use in high resolution combat simulations such as DYNTACS X. The fundamental concept used in comparing alternative routes is the minimization of perceived threat under the constraint of attacking a target. Three alternative threat perception models were hypothesized and compared experimentally. The experiments consisted of map exercises using helicopter pilots with combat experience as subjects. The subjects selected routes in a variety of

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combat situations, and the model generated routes using inputs solicited from the subjects; then the subjects compared their routes with the model routes. One of the three threat perception models performed better than the others and appeared to produce routes that were acceptable to the pilot subjects.

FOREWORD

This report describes research conducted by the Systems Research Group under Contract DAA625-70-C-0311 with the U.S. Army Combined Arms Combat Developments Activity (USACACDA), Ft. Leavenworth, Kansas. The objective of this research is to develop DYNFLITE, a helicopter route selection model.

Conclusions drawn in this report represent the current views of the Systems Research Group, Department of Industrial and Systems Engineering, The Ohio State University, and should not be considered as having official USACACDA or Department of Army approval, either expressed or implied, until reviewed and evaluated by those agencies and subsequently endorsed.

The cooperation received from Army agencies has been extremely helpful. In particular, we wish to acknowledge the U.S. Army Aviation School, Fort Rucker, Alabama and the U.S. Army CDC Experimentation Command, Fort Ord, California for providing those enthusiastic helicopter pilots as subjects in the experiments. Without their suggestions and evaluations, this research would not have been possible.

We would like to acknowledge the important contributions of Lois Graber and Jean Johnson, who patiently typed and proofread the text.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

Figure		Page

Figure		Page

Figure		Page
E. 38	Plot of Interactions by Subject Pair (Combined Data Sets). . .	443
E. 39	Plot of Interactions by Subject Pair (Combined Data Sets). . .	444
F. 1	Analysis of Variance for Subject 6	487
F. 2	Analysis of Variance for Subject 7	488
F. 3	Analysis of Variance for Subject 8	489
F. 4	Analysis of Variance for Subject 11	490
F. 5	Analysis of Variance for Subject 12	491
F. 6	Analysis of Variance for Subject 13	492
F. 7	Analysis of Variance for Subject 6 (Trial Two only)	493
F. 8	Analysis of Variance for Subject 7 (Trial Two only)	494
F. 9	Analysis of Variance for Subject 8 (Trial Two only)	495
F. 10	Analysis of Variance for Subject 11 (Trial Two only).	496
F. 11	Analysis of Variance for Subject 12 (Trial Two only).	497
F. 12	Analysis of Variance for Subject 13 (Trial Two only).	498
F. 13	Analysis of Variance for Subjects 7 and 11	499
F. 14	Analysis of Variance for Subjects 8 and 12	500
F. 15	Analysis of Variance for Subjects 7 and 11 (Trial Two only) .	501
F. 16	Analysis of Variance for Subjects 8 and 12 (Trial Two only) .	502
F. 17	Plot of Block Effect by Subject (Block One-Phase II, Block Two-Trial Two).	503
F. 18	Plot of Route Effect by Block and Subject (Block One-Phase II, Block Two-Trial Two)	504

Figure | Page

LIST OF TABLES

Table		Page

SUMMARY

A very important factor in a high resolution land combat model is the route selected to attack enemy units. This route is certainly related to the positions of detected surviving enemy weapons since the attack route is usually chosen to seek cover from enemy weapons until the enemy is to be engaged with destructive fires. Thus, the attack route is affected by random variables in a high resolution simulation and can not be prespecified as input data. Accordingly, DYNTACS X has a route selection for helicopters in attacking an enemy target complex. However, this model is essentially an adaptation of the ground unit route selection model and has not been validated. This report describes research conducted to develop a valid helicopter route selection model called DYNFLITE.

To begin the research program, informal discussions were held with pilots to gain some initial insight into the route planning decision process. During these discussions, the pilots stated that they develop route plans so as to minimize "exposure" to the enemy. It was unclear what units are used to measure exposure and upon what variables exposure is dependent. However, it was suspected that exposure is somehow related to a pilot's perception of his chances for survival. In the absence of other information, the concept of "perceived threat" was developed as a measure of exposure and three alternative models to relate perceived threat to the variables of a route selection situation

were proposed. In addition, the route planning task was formulated as a multiple alternative decision problem.

As the next step, an experiment was conducted among qualified helicopter pilots at Fort Rucker to determine perceived threat for each pilot according to each of the three proposed models. This experiment is known as the Phase I Experiment. As a parallel effort a route selection algorithm was developed that accepts perceived threat as measured by any of the three models as input, and predicts an attack route on the basis of minimum total route threat. An important assumption of this algorithm is that the perceived threat of a complete route is the sum of threats perceived for individual route segments. Analyses of the pilot data from the Phase I Experiment showed that the simple additive relationship may not be a satisfactory approximation for one of the three perceived threat models, i.e., the Acid Test Model.

Next, another experiment was conducted among the Phase I subject group members to determine their actual performance in a route planning task. For convenience, this experiment was conducted during the same session as the Phase I Experiment.

Continuing, the perceived threat data gathered during Phase I were prepared as input to the route selection algorithm. Also, descriptions of the Phase I route selection situations were prepared as input to the algorithm. For each subject, the algorithm was then exercised to prepare a series of alternative route predictions for each route selection situation based on the three models of of threat perception.

As a final step in the procedure, a Phase II Experiment was conducted in which members of the Phase I subject group at Fort Rucker were asked to rate the predicted alternatives relative to the routes they planned during Phase I. Data gathered during this experiment were then used not only to evaluate the route selection model and the models of perceived threat, but also to study the characteristics of the underlying decision process itself.

The results indicate that considerable variation exists between subjects so that it may be impossible to develop a single route selection model that is completely acceptable to all individuals. However, the decision behavior of a predominant class of decision-makers is apparently described to an acceptable degree by the route planning model, if the threat perception model known as Model One is used to measure perceived threat. Unfortunately, the model does not describe decision behavior equally well in all route selection situations. Model One is completely insensitive to differences among the pilots, and it assumes that the route threat is the sum of the exposure times to each enemy weapon. More experimentation was required to resolve this question as well as others.

Another important experiment was conducted at Fort Ord using experienced pilots who had also been trained in helicopter tactics in a mid-intensity combat environment. This experiment at Fort Ord was conducted in the same format as the experiment at Fort Rucker; however, the results showed a strong preference for a different model, i.e., the Acid Test Model, than Model One. The Acid Test Model is personalistic in the sense that pilot inputs are required

to specify perceived threat as a function of enemy weapon distance, azimuth, and exposure time.

The conclusion drawn from both of these experiments is that DYNFLITE should use the Acid Test Model to measure perceived threat. Also, considerable variation exists in the pilot preferences for the model routes as compared to a manually selected route. The experiment revealed cases where the pilot preferred the model route and cases where a manually constructed route was preferred. On the average, the manual routes were preferred but the preference was mild.

CHAPTER 1

RESEARCH OBJECTIVES AND PLAN

by Gordon M. Clark

Introduction

The main purpose of the research described in this report is to develop a model, called DYNFLITE, to predict the route selected by a helicopter pilot in attacking a target. This model should be capable of use in DYNTACS X (Clark and Hutcherson, 1971), a simulation of engagements among battalion-sized combat units involving ground and helicopter units. Also, the development of DYNFLITE provides spillover benefits by giving insights into the tactical decision process and the training of combat pilots. The motivation for this research is that DYNTACS X already has a route selection model for helicopters; however, the model for comparing alternative routes has not been validated and methods for soliciting input parameters from qualified pilots require development. As currently formulated, the model is based upon hypotheses derived from current doctrine and discussions with aerial vehicle pilots with operational experience. However, there is no experimental or operational evidence to support the models at this time. Carefully planned experiments need to be conducted to identify the underlying decision processes and to verify the decision concepts involved.

Research Objectives

Thus, the desired output from this research is a method for obtaining tactical decision parameter inputs and a corresponding model for use in DYNTACS X. These inputs and model should be capable of predicting the attack route in diverse situations likely to be encountered in the combat simulation. The input tactical parameters should specify the tactical doctrine to be employed in selecting the attack route.

In order to develop this model, decision and value-theory concepts will be used as elements of the route selection model. Thus, an intermediate objective is to determine whether decision and value-theory concepts can be used to explain the behavior of a military decision-maker, viz., a helicopter pilot, in the face of a decision under pressure.

DYNTACS X Helicopter Route Selection Model

A brief overview of the DYNTACS X attack route selection model developed by Clark and Hutcherson (1971) is provided as background to the research described in this report. This discussion assumes that a helicopter unit, simulated by DYNTACS X, has been requested to attack a target complex by a ground unit.

Three different phases of the helicopter route selection problem are represented by DYNTACS X. These phases are:

1. selection of a cross country route to the target complex area,
2. selection of a target search route, and
3. selection of a target attack route.

The model for phase 1 involves the use of a modified version of the ground route selection model (Clark, 1969b). Thus, the assumptions are that the ground route selection procedure is valid and that helicopter pilots react in the same fashion as ground unit commanders with respect to cross country route selection problems. Of course, the helicopter route selection model can accept decision variables that represent the unique tactics of helicopters, but the model structure is basically the same.

The models for phases 2 and 3 above use procedures that are unique to the aerial vehicle route selection process. Target search routes are selected as follows:

1. define the mission operations area as a circle of specified radius centered at the reported target location,
2. choose a point whose coordinates are distributed over the circle according to a conical distribution, and
3. continue selecting points until an adequate number of points to describe the route have been selected.

The rationale for the search route selection procedure is as follows. First, it is assumed that pilots searching for targets tend to sequentially investigate potential target locations. Second, no theoretical basis exists for determininistically determining how a pilot might identify potential target locations; however, one might postulate that these positions would be more concentrated in the vicinity of the reported target position. Therefore, a conical distribution is selected as being representative of the process.

Several different solutions to the target attack route selection problem exist. In any case, the attack phase starts after the target has been detected (by the attacking helicopter or a scout) and a decision to attack has been made. The original model (Clark and Hutcherson, 1971) employed a running fire attack where a route is drawn through points starting at the current helicopter position and leading toward the target position until the weapon can be fired. After an initial attack, subsequent attacks using running fire can be made using routes leading toward the target position from directions that are randomly selected but subject to the constraint that they originate from the "friendly side." Modifications by Army agencies (MICOM and CACDA) have added hover fire attacks using "pop up" tactics; moreover, these hover fire attacks can be coordinated with target acquisition activities of scout helicopters.

Scenario for this Research

A specific tactical scenario has been selected for this research that provides a setting consistent with the possible situations represented by DYNTACS X. The intent of this scenario is to capture the essential elements of the multitude of situations represented by DYNTACS X and provide an experimental setting that is consistent with the level of effort provided for this research. The primary requirement is that a valid route selection model for this scenario would provide confidence in the validity of DYNTACS X while using this same route selection model.

The problem commences with the helicopter on the ground some distance from the point of conflict. A request for aerial fire support is received by

radio, and this request contains all the information needed by the pilot in planning his attack. Prior to take-off the pilot sketches, on a map at his knee, the location of the target and any other known enemy weapons in the vicinity. He also sketches the route to be followed and the probable point at which he will deliver his ordnance against the target. The route plan is, of course, tentative and may change as the mission actually develops. Nevertheless, it is the initial plan that is of interest in the present research. In performing the planning task the pilot is under pressure to render a speedy decision. He also prepares the plan realizing that he will face a hostile opponent while executing the plan. Consequently, this decision task has all the elements of an attack upon an enemy target position with the exception of the search for the target.

Some Benefits

Research in the route planning decision process is of importance for several reasons. First, route planning is a fundamental and very common decision process of combat, both for ground vehicles and for aerial vehicles. A valid model to explain decision behavior in this task would be a contribution to a better understanding of combat processes in general. Also, military planners have made extensive use of simulations to describe combat operations in order to study the effects of variations in weapon system characteristics, tactics and doctrine[1] on the operational performance of combat units. Any detailed

[1] The following definitions are offered from Webster's New International Dictionary, Second Edition: Tactics 1. The science or art of disposing and maneuvering troops or ships in action or in the presence of the enemy. 2. ..... Doctrine 1. ..... 2. A principle or position, or the body of principles in any branch of knowledge....

simulation of this type requires that one be able to predict the routes that are selected by combatants. For example, Clark (1969b) shows that the routes selected by armored vehicles can affect the intervisibility relationships that exist between them and thus affect their ability to fire on one another. Also, characteristics of the terrain surface in the vicinity of a vehicle can change drastically as routes are changed, thereby producing effects on the mobility of the vehicle. However, it is not enough to simply prespecify the routes that combatants will follow, for the decision-maker selects these routes in combat to take advantage of the known disposition of the enemy, and this knowledge changes probabilistically as a function of time.

Next, the research may very well produce significant practical benefits in terms of insights into the decision process itself. For example, it may be that a fundamental limitation on the performance of a pilot in the route planning task is his inability to accurately perceive all the important variables of the situation. One result would be that he feels he is performing according to prescribed doctrine when in fact he is not. If this were the case, the performance of the decision-maker might be more important as a limit on unit operational performance than either prescribed doctrine or the physical capabilities of the unit's weapons. Such a result would indicate a need for some sort of aid in the route planning task. Also, such behavior in the route planning task most probably would indicate the existence of the same phenomenon in other types of military decisions under pressure.

Another insight would be provided if it were discovered that two or more distinct and consistent patterns of decision behavior exist among pilots. Such a finding would indicate that it may be impossible to develop one universally acceptable model of the decision process. The design philosophy of detailed combat operations simulations would be drastically altered by this finding. Also, if one or more of the patterns of behavior were considered to yield poor combat results then a change in training syllabi or in pilot selection procedures might be indicated.

Another insight would be provided if it were found that certain pilots are more consistent in their decision performance than others. For example, when faced repeatedly with the same tactical situation, some pilots might almost always select essentially the same attack route while others might select routes that vary extensively from one trial to the next. Would such a finding indicate simple psychological differences between pilots or could such differences be traced to variations in experience? Was the formal training experienced by the pilots the same? Were the pilots exposed to essentially the same enemy for about the same amount of time? Numerous research programs could be pursued to study variations in decision performance of the type described above.

Next, in much of the above discussion it was implied that the route planning research program could yield insights into the decision process that might be constructively incorporated into the procedures used to select and train pilots. However, a valid model of the route planning process could be used directly in the pilot training program itself. For example, the model could be used in

studies to isolate good decision principles, perhaps on the basis of an objectively determined survival probability. The model could also be used as a device to train decision makers in the application of good decision principles and to measure their progress in the training program. Thus, the route planning model has a broad potential for use in training.

Some Related Research

A review of the literature concerning military decision-making under pressure to assess available methodology for modeling route selection only confirms the need for more research in this area. This review included methodology for determining when to fire at enemy weapons and what target to select in order to take advantage of available methodology. Studies of this important decision process are very limited in number. Nevertheless, two examples were found whose results merit examination.

Olson (1970) performed research to determine the firing decision behavior of a tank commander in a stationary firing position when confronted with an enemy tank that is also stationary. In the situation studied it was possible that the decision to fire could result in the enemy tank being destroyed before being able to return fire. However, it was also possible that firing resulting in a miss could motivate the enemy to fire.

Independent variables in the study were target range, the degree of cover provided the target tank, the aspect of the target and previous engagement history. It was found that the decision to fire or not fire could be predicted quite well from

a knowledge of the independent variables included in the study. Tank commanders were found to be quite conservative in this decision context in that they tended to fire as soon as they felt that firing would decrease their chances of being hit by the enemy. With his model, Olson attempted to prodict the range at which all tank commanders would fire. He then assumed that the proportion of the population that would fire at any greater range could be predicted as a linear function of range. Unfortunately, predictions based on this assumption were not as accurate as desired.

Parry (1971) extended Olson's work to treat the case of a fixed firer, moving target. The effects of eleven independent situation variables on four response variables were treated in this study by using a 1/16 replicate of a 2^{11} factorial design. All of the response variables were related to detection and engagement. A very interesting aspect of the study was the analysis required for such a complex experimental design. However, one very important insight into the decision process was also determined. It was found that the tank commander's decision behavior is a very complex function of the situation variables. Indeed, most of the variation in the response variables was found to be attributable not to basic variations in the independent variables themselves but to interactions among the variables. For example, the turret position of the enemy tank coupled with the movement history of the tank might lead the commander to believe that the enemy has detected his position.

The two studies discussed above involved one or more decisions in which two alternatives exixted. The number of studies of military decision processes

involving the selection of an alternative from a multiplicity of alternatives is more limited yet. First, let it be noted that had Olson and Parry extended their work to treat multiple targets, then a multiple-alternative decision process would have resulted. The decision would not only have been whether to fire but also at which target. Both Olson and Parry demurred from such an extension based on the complexity of the processes involved.

Next the review considered available route selection models, and several of these models will not be outlined.

One of the earliest representations of the military route selection process appeared in a combat simulation known as CARMONETTE. As described by Zimmerman and Kraft (1957), the route selection model uses the concept of tactical areas to define potential assault routes for a tank company and its supporting weapons. For analysis purposes, the number of possible assault routes is limited to approximately ten. The tactical areas are specified by classifying the terrain into irregularly shaped areas such as hilltops, valleys, forests, fields and villages. Thus, each area is approximately homogeneous with respect to an important environmental characteristic.

Once the potential assault routes are identified, each is evaluated to determine the casualties and travel time that the company would expect to experience if the route were actually followed. In turn, these two measures are combined through a weighting procedure to produce a relative "desirability" for each route. Finally, the route possessing the greatest "desirability" is selected for implementation.

The model described above employs several important concepts which have been exploited in the helicopter route planning model described in Chapter 2. For example, the environmental characteristics of the terrain are considered in developing a set of potential routes. Also, a measure is developed with which to evaluate each potential route, and this measure is sensitive to the variables describing the tactical situation. Unfortunately, the route selection procedure has never been validated as a descriptive model.

A later version of CARMONETTE contains an entirely different route selection model and is described by Adams, et al. (1961). The terrain is organized into a 36 x 36 array of equal area grid squares with the environmental characteristics of each square quantified by a set of descriptive codes. An element can occupy any position on the battlefield, and its local environment can be determined; however, the position of the element is determined only to the center of the nearest grid square. Other significant features of the model may be summarized as follows:

1. The movement trace of an element (e.g., a tank) is represented as a series of connected line segments extending between adjacent grid square centers.

2. An element plans its route by examining the desirability of traveling to each of the eight grid squares adjacent to the present grid square.

3. The movement decision is performed by a Monte Carol Move Selection Model.

Again, this model has not been validated as a descriptive route planning model.

Another route selection procedure which was obviously influenced in design by the second CARMONETTE model is that which is incorporated into the

Signal Corps ground Combat Simulator. This model was summarized by USACDC (1963) and is a division-level simulator emphasizing information and communication flow. Instead of treating individual vehicles, the model describes the activities of a tactical unit.

The terrain is organized into grid squares, and each square is given a set of indices specifying the local environment. In turn, these indices are used in the route selection procedure to compute a grid terrain index which represents the "cost" of leaving a grid. No research has been performed to determine how well the model performs as a descriptor of the tactical unit route selection process.

The route selection model having the most influence upon this research is a model used to select routes for ground units in DYNTACS X (Clark, 1966). Recall that the existing DYNTACS X helicopter route selection model is a modification of this model. The ground route selection model uses a dynamic programming algorithm to select a route of "least tactical difficulty" through a route selection grid laid down along a specified axis of advance. The area covered by the grid is known as the "route selection area" and represents the decision maker's spatial planning horizon. Many elements of this model have been used as a basis for the model to be discussed in Chapter 2.

In addition, research has been conducted by Captain Donald Shive (1976) for his Master's Thesis at The Ohio State University to validate the DYNTACS X ground route selection model. Shive solicited inputs for the model from experienced army officers at Fort Knox, tested model assumptions using these inputs,

and attempted to predict routes selected by these officers by the route selection model. The basic model assumptions were verified; however, several extensions or modifications to the model were recommended by Shive to improve its predictability.

A final example of a descriptive model of the military route selection process is incorporated into the SIAF model developed by TRW (1971). This procedure was established to represent the route selection activities of a small dismounted patrol. Again, the terrain is divided into grid squares and a dynamic programming algorithm is employed to select the optimal route. The route consists of a series of connected line segments joining adjacent grid points, but each segment is evaluated on the basis of its "utility." This "utility" value is determined as a linear combination of terms relating to such factors as the probability of detecting the enemy, the probability of being detected and the difficulty of movement along the segment. Certain grid points can be identified as positions to be avoided (for protection) or as positions to be approached (for observation). Other grid points can be identified as positions through which a route cannot pass under any circumstance. These points are most representative of obstacles to movement. No attempt to validate the SIAF route selection model has been made.

In conclusion, little research has been conducted to understand even the decision when to open fire which is a simple binary go-no go military decision under pressure. For the more complex route selection decision which is a pressured military decision involving multiple alternatives, much less is known.

Although several models have been proposed, little research has been performed to validate them.

The Research Plan

At the outset of the research program, informal discussions were held with pilots to gain some initial insight into the route planning decision process. During these discussions, the pilots stated that they develop route plans so as to minimize "exposure" to the enemy. It was unclear what units are used to measure exposure and upon what variables exposure is dependent. However, it was suspected that exposure is somehow related to a pilot's perception of his chances for survival. In the absence of other information, the concept of "percevied threat" was developed as a measure of exposure and three alternative models to relate perceived threat to the variables of a route selection situation were proposed. In addition, the route planning task was formulated as a multiple alternative decision problem.

As the next step, experiments were conducted among qualified helicopter pilots to determine perceived threat for each pilot according to each of the three proposed models. This experiment is known as the Phase I Experiment (Chapter 3). As a parallel effort a route selection algorithm was developed that accepts perceived threat as measured by any of the three models as input and predicts an attack route on the basis of minimum total route threat (Chapter 2).

Next, other experiments were conducted among the Phase I subject group members to determine their actual performance in a route planning task.

For convenience, these experiments were conducted during the same sessions as the Phase I Experiments.

Continuing, the perceived threat data gathered during Phase I were prepared as input to the route selection algorithm. Also, descriptions of the Phase I route selection situations were prepared as input to the algorithm. For each subject, the algorithm was then exercised to prepare a series of alternative route predictions for each route selection situation based on the three models of threat perception.

As a final step in the procedure, Phase II Experiments (Chapters 4, 5, and 6) were conducted in which members of the Phase I subject group were asked to rate the predicted alternatives relative to the routes they planned during Phase I. Data gathered during these experiments have been used not only to evaluate the route selection model and the models of perceived threat, but also to study some of the decision performance questions outlined in an earlier section of this chapter.

Finally, conclusions are drawn in Chapter 7 from these experiments to determine a decision model (DYNFLITE) for use in the DYNTACS X route selection model.

CHAPTER 2

A ROUTE PLANNING MODEL

by Don C. Hutcherson

Introduction

In this chapter attention is directed to formulation of a model of the route planning task. This model will embody many decision and value-theory concepts and is intended as a descriptive, rather than a normative, model of pilot decision behavior in the task of interest.

As a first step, a possible conceptualization of the decision process employed by a pilot in planning a route is presented. This conceptualization is based upon the assumption that pilots perform according to a set of well known principles accepted as elements of decision and value-theory and which have their counterparts in psychophysical theory.[1] However, it is not intended that a decision model be derived which is actually a representation of the thought process conceptualization. Instead, the decision model to be developed is intended merely to predict the final results of that decision process. The decision process conceptualization is developed to promote understanding and to serve as a framework of thought within which a decision model might be developed. The process conceptualization has not been validated, whereas

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[1] Psychophysics in simplest terms, may be defined as the field of study of the experimental psychologist that is involved with man's ability to discriminate. From Galenter (1962), questions that the psychophysicist might ask are: "What is it that people do when they discriminate, how do they do it, how can we understand it, what are its limits .....?"

considerable effort has been expended to validate the decision model as a predictor. Chapters 3 through 6 present a detailed description of this effort.

The Decision Process

The route-planning task is conceived to be a task conducted under considerable pressure for a speedy decision. Therefore, it is assumed that the task is conducted almost exclusively as an intuitive and subjective exercise which yields decisions that would be considered less than optimal even by the decision maker, were he to have sufficient time to conduct a thorough analysis of the situation. This assumption is in agreement with the hypothesis stated by Morris (1964) that decision processes pressured by time tend toward intuition and away from analysis.

Nevertheless, the process does contain elements that are common to most decision problems. The pilot conducts an implicit search for alternatives. He employs a decision rule to evaluate the alternatives as they become apparent. Finally, he employs a stopping rule to determine when he should cease searching for new alternatives and accept one of the ones he has found as his plan of action. This stopping rule could specify termination of search with the first feasible alternative.

We are in agreement with Morris (1964) in his view that the potential for effective decision-making in a decision task is limited during the first phase of the decision process; i.e., during the search for alternatives. It is hypothesized that the pilots take a rather simplistic view of the decision alternatives available to them. They are limited by their capacity to perceive all

the complexities of the situation and the terrain over which routes are to be planned. Subject to time constraints, they successively isolate satisfactory alternative approaches to attacking the target and from this set they choose one they perceive as best. The March-Simon (1958) hypothesis provides a basis for this principle of route selection:

> "Most human decision-making, whether organizational or individual, is concerned with the discovery and selection of satisfactory alternatives; only in exceptional cases is it concerned with the discovery and selection of optimal alternatives."

Since an optimal alternative is one that is demonstrably the best of all possible alternatives, the pilots are less than optimal in their decision behavior. This view is certainly confirmed by a mass of literature concerned with learning and other psychophysical phenomena.

We further hypothesize that fairly simple decision rules are applied in isolating and evaluating the various route alternatives. A possible alternative is analyzed first to determine whether it satisfies all the constraints placed upon it by the facts of the scenario and by the performance characteristics of the weapon system being used. That is, to be a satisfactory alternative the route must permit an attack upon the target. Routes passing this aspiration threshold test are then evaluated using simple decision rules and the best alternative is subsequently chosen.

The contention of the previous paragraph is certainly well-founded in the results of numerous psychophysical studies. Indeed, experimenters have found that regardless of the complexity of a decision task, the behavior of a subject

can often be described[2] with very simple linear models. Moreover, in complex decision tasks, subjects tend to process very limited amounts of information in performing the tasks. This is not to say that subjects recognize their limited capabilities; rather, this is the way people behave. A thorough discussion of studies conducted along these lines and evidence to support our contentions are contained in the recent work by Slovic and Lichtenstein (1970).

The Decision Model

From the discussion of the previous section there is the suggestion that the decision model to be developed should be able to isolate acceptable alternatives, evaluate the alternatives according to some measure of worth (probably subjective) and yield as the answer that alternative among those examined which is judged best by the decision rule being used. The proposed model does in fact possess all these characteristics, and they will be discussed throughout the remainder of this chapter. The discussion begins with a derivation of the decision rule.

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[2] Emphasis has been added to indicate that while behavior can be described by such simple models, the models in themselves do not necessarily reveal an explanation of the behavior. Fortunately, description is the primary goal of the present research. However, some doubt is cast on the concept of simplicity in at least one type of military decision-making problem by the results of Parry (1971) discussed in Chapter 1 (see page 9).

The Decision Rule

The route planning task may be characterized by a set of alternative route plans a_i, a set of payoffs V_j and a set of probabilities p_{ij}, with a particular p_{ij} specifying the probability that V_j is realized, given that route plan a_i is followed. Now, given a route alternative a_i, there are four possible future states O_j that can exist after completion of the mission:

O_1 - both the target and helicopter fail to survive;

O_2 - the target is dead, but the helicopter survives;

O_3 - the target survives, but the helicopter is killed; and

O_4 - both the target and the helicopter survive.

The payoffs V_j are some unknown function of O_j; that is $V_j = F(O_j)$.

The decision rule is to provide a principle of choice between the alternatives a_i, $i = 1, 2, \ldots$. It should be representative of that used by a helicopter pilot and it most probably should utilize the information provided by V_j and p_{ij}. The preferred alternative selected according to the decision rule is given the symbol a^*.

There are a number of decision rules that might be applied to select a^*. The decision-maker could view the decision as one under uncertainty, one under risk or one under assumed certainty. In the first case the decision-maker is unable or unwilling to attach any values to the probabilities p_{ij}. In the last case, it is assumed that there is but one possible future O_j associated with a given route plan alternative a_i. A view that the decision is one under risk offers a middle ground in which values are assignable to the probabilities p_{ij}.

Under assumed certainty, each route alternative a_i would have associated with it one of the four futures O_j, $j = 1, 2, 3, 4$. That is, for a_i, if O_m is assumed, then $p_{i,m} = 1$, $p_{ij} = 0$ for $j \neq m$, and the payoff for a_i would be V_m. Given that a different value of m could be assumed for each i, $i = 1, 2, \ldots,$ the decision rule might be to select the plan that results in the greatest payoff V^* where $V^* = \max_i \sum_j p_{ij} V_j$. Some other procedure such as coin tossing could be used if more than one route produced the same future or if more than one future realized by the plans had an equivalent payoff. One might suspect that pilots would associate with all routes either possible future O_2 or possible future O_4 above, and possibly only future O_2 might be used. In this last case, a lot of coin tossing would be involved in arriving at a decision since a unique value for a^* would never be produced by the decision rule employing V^*.

Under uncertainty, several decision rules, or principles of choice, have been proposed. After Morris (1964), notable examples are: the Laplace Principle, the Maximin Principle, the Hurwicz Principle and the Savage Principle. In our context the variation among these principles again lies in the assumptions made about p_{ij}.

The Laplace Principle simply states that one should select the alternative which maximizes expectation assuming equally likely futures. In the problem at hand, the principle yields nonsensical results in that all p_{ij} assume the same value. The principle does not lead to a choice since all alternatives have the same value. The only way the principle could lead to a choice would be for some of the p_{ij} values to be a priorily set to zero. But then this would be a

departure from the Laplace Principle. The principle also has a fundamental weakness in the problem at hand for the pilots probably do not think of O_2 and O_4 as having probabilities equivalent to O_1 and O_3.

The *Maximin Principle* states that one should select the alternative that maximizes the minimum payoff. However, in the problem at hand, the minimum payoff is the same for all alternatives so the principle does not lead to a decision. Also, the principle is probably much too conservative considering the differences between O_2, O_4 and O_1, O_3.

Unmodified, the Hurwicz Principle fails to lead to a decision in our decision problem for the same reason that the Maximin Principle failed. However, it can be modified and used. The modified principle is defined as follows: For each alternative a_i *define an index of optimism* α_i that expresses the degree of optimism the decision-maker feels for the alternative. If he is extremely optimistic set $\alpha_i = 1$. If he is extremely pessimistic set $\alpha_i = 0$. Then select as a^* the alternative a_i having the maximum value of α_i. Of course, this principle of choice is no more than the principle that has always been used for intuitive decision-making. Consequently, the principle really contributes nothing new in the present context.

The Savage Principle operates on a quantity known as regret and defined as the difference between a given payoff and the maximum payoff that could be realized for the possible future under consideration. The principle fails as a principle of choice for the same reason that the Maximin Principle and the unmodified Hurwicz Principle failed.

Considering the deficiencies outlined above, it appears that the route planning task as it has been formulated cannot be structured as a classical decision under assumed certainty or as one under uncertainty. We, therefore, turn to a view of the decision as one under risk.

Edwards (1955) has described four models which are related and which have been used extensively in studies of risky decision-making behavior. These models assume that a decision maker will choose the alternative that maximizes his expected payoff, whether the payoff be measured objectively or subjectively. Expectation in these models is computed using both objective and subjective probabilities.

The first model is called the expected value (EV) model, with the expected payoff computed using objective measures for both payoff and probability. Such a model would be of use in the present context only if the payoffs V_j and the probabilities p_{ij} were measured in an objective fashion. Since the decision rule is to represent a basically subjective process we reject the EV model in lieu of more subjectively based candidates.

The next model computes expected payoff with subjective probabilities and objective payoff measures. The expected payoff is called subjectively expected money (SEM). Such a model is more appropriate to our needs than the EV model in that it becomes more sensitive to variations across individuals through the use of subjective probabilities. If an objective payoff measure such as death of the target or survival of the helicopter were used, then the model

would be exactly suited. For example, we could use $\left\{ \begin{array}{l} V_j = F(O_j) \\ p_{ij} \end{array} \right\}$

as the components of the model where the p_{ij} are measured subjectively and

$$F(O_j) = \begin{cases} 1 \text{ if } j = 2,4 \\ 0 \text{ if } j = 1,3 . \end{cases}$$

In this model, the only matter of concern is survival of the helicopter.

The expected utility (EU) model employs objective probabilities in computing expected payoff, but the payoff is measured by utility (subjective value). This model would be applicable in the present context if objective probabilities were appropriate, and if the utility function $V_j = F(O_j)$ could be determined. It is another personalistic model, but this time the sensitivity to individual differences arises through the subjectivity of the payoff. The EU model is not as applicable in the present context as the SEM model because of its use of objective probabilities. While one might visualize the existence of an objective measure of payoff as was done for the SEM model it is difficult to perceive how objective probabilities could be determined by a pilot planning an attack.

Finally, the subjective expected utility (SEU) model employs both subjective probabilities and subjective values to measure expected payoff. This model is the most sensitive to variations among decision makers, and from this point of view might be the most desirable model of the four for our use. It is also the most general model for two reasons. First, it could turn out that subjective probabilities closely approximate objective probabilities.

Second, the utility function $F(O_j)$ could very well approximate an objective function such as that used in the example of the SEM model. Thus, all the previously cited models could conceivably be accommodated within the SEU model representation. To use the SEU model one would have to determine the utility function $F(O_j)$ and the subjective probabilities p_{ij} for each alternative a_i. One would then select a^* as the alternative associated with

$$V^* = \max_i \left\{ \sum_{j=1}^{4} p_{ij} F(O_j) \right\} .$$

A potential difficulty underlying the use of all the cited risky decision models in predicting human behavior is that the expectation maximization decision rule is sometimes a fairly poor predictor of apparently idiosyncratic behavior. There is the phenomenon, called risk by many (unfortunately), that apparently enters the decision process and which numerous authors have blamed for the poor showing of the decision rule. For example, in a gambling decision in which the utility for money has been determined for an individual, and in which subjective probabilities have been elicited, expectation maximization does not predict the gambler's decision. He may elect not to gamble if the stakes are too high or if the probability of winning is too low, even though the expected utility of gambling is greater than that for sitting tight.

A variety of theories and near theories have been proposed to correct for risk. Perhaps the oldest treatment is incorporated in the "expectation-variance" principle embodied in most introductory discussions of utility models.

This principle states that a decision maker faced with several alternatives will act so as to maximize his expected utility. That is, as stated previously, he will choose that alternative that yields maximum expected payoff with payoff measured in terms of utility. However, faced with two or more alternatives to which he is otherwise indifferent, he will choose that alternative that exhibits the least variance in outcome. For example, consider the two alternative gambles A and B described by the following decision matrix.

	Outcome	
Gamble	1	2
	p(1) = .5	p(2) = .5
A	$2.00	-$2.00
B	$1.00	-$1.00

The two alternatives are equivalent with respect to expected payoff ($0), but the expectation-variance principle predicts that the decision maker, nevertheless, would choose alternative B over alternative A since the variance of alternative B is $1.00 while the variance of alternative A is $4.00. Thus, the expectation-variance principle takes the variance in outcome of an alternative as a measure of the risk of that alternative. However, as stated by Pollatsek and Tversky (1969), empirical evidence for systematic variance preferences is somewhat inconclusive.

Other approaches to the study of risk in decision making have been made by Coombs and his associates (cited extensively by Pollatsek and Tversky, 1969 and by Wendt, 1970). These studies have explored the variables affecting the perception of risk and have also dealt with the question of how perceived risk affects preferences. The theory postulates that each individual has a most preferred risk level and that instead of trying to minimize variance in outcome one tries to minimize the deviation of risk from the ideal. An abundance of other theories of risk are cited by Wendt (1970) in his excellent review of utility and risk, and Pollatsek and Tversky (1969) examine the perception of risk from the standpoint of measure theory to develop a quantitative psychological theory of risk.

At this point in the route-selection research, there is no basis upon which to choose a particular theory from among the many to predict pilot decision behavior. One could choose a very complicated "new" theory or a very simple "old" theory. However, in the absence of even the first indication of how pilots behave, it has been decided that the choice of a simple "old" theory that has enjoyed some success is probably the most prudent approach. Should the results of the research turn out to be less than satisfactory, it would remain the task of future researchers to enrich the theory. Edwards' (1955) SEU model serves as a starting point, with the expectation-variance principle being incorporated to account for risk.

Since the SEU model is to be used, $F(O_j)$ is defined as a utility function and p_{ij} is a subjective probability. Thus, the expected utility of alternative a_i is

$$U_{a_i} = \sum_{j=1}^{4} p_{ij} F(O_j),$$

the expected outcome of alternative a_i is

$$E_{a_i} = \sum_{j=1}^{4} p_{ij} (O_j)$$

and the variance of a_i is

$$V_{a_i} = \sum_{j=1}^{4} p_{ij} (O_j)^2 - E_{a_i}^{\;2} .$$

According to the expectation-variance principle, the pilot will choose a_i so as to maximize U_{a_i}; and, failing to find a unique course of action, will choose so as to minimize V_{a_i} among those alternatives to which he is otherwise indifferent.

Now, one may intuitively argue that during route planning, a pilot cannot force himself to consider his own demise. It is surmised that investigations conducted to elicit his utility function would find that he possesses practically

infinite disutility for outcomes which include his failure to survive. By comparison, he would possess almost infinite utility for outcomes that include his survival. Also by comparison, all outcomes that include his survival would be assigned utilities that are almost identical. Since utilities are unique up to a positive linear transformation, an approximation for V_{a_i} can be obtained by

$$F(O_j) = \begin{cases} 1 \text{ if } j = 2,4 \\ 0 \text{ if } j = 1,3 \end{cases} . \text{ Thus}$$

$$U_{a_i} = \sum_{j=1}^{4} p_{ij} F(O_j)$$

$$= p_{i2} + p_{i4} = P_i ,$$

where P_i is simply the probability of surviving the mission, regardless of whether the target lives or dies.

From the above relation one may predict that the pilot will choose that alternative which maximizes his chances for survival, a result that is intuitively appealing. However, carried to the extreme, application of the decision rule would predict that the pilot will simply choose not to conduct a mission at all since considerations of the chances that exist for destroying the target by employing a given route alternative have been dropped from the decision rule. To avoid such a result, the only alternatives that will be allowed are those that produce some positive probability of destroying the target. In other words, the pilot is constrained to choose a route which does not violate the requirements of an attack, that are imposed by the physical limitations of the ordnance to be delivered. After having achieved this minimum threshold with his route, survival will be the pilot's only consideration.

One may also note from the utility relation that, faced with alternatives to which he is otherwise indifferent, the pilot will have to employ an alternate rule such as flipping a coin to decide which alternative to choose. Minimization of variance does not lead to a decision since, in this case,

$V_{a_i} = P_i - P_i^2 = V_{a_k} = P_j - P_j^2$ when $P_i = P_j$.

Practical Application of the Decision Rule

Discussion of the decision rule derived for the route-planning decision model has indicated that one simply has to determine P_i for each alternative plan a_i in order to apply the decision rule. However, there are at least two reasons why this is not the approach that has been followed in practice. Of most importance is the fact that P_i is a probability of survival which must be elicited from the decision makers themselves. It was felt that it might be very difficult to obtain directly from a decision maker an accurate estimate of his own chances for survival. Of secondary importance is the fact that for reasons to be explained, maximization of P_i requires that an exponential criterion function be employed. To avoid potential computational difficulties, a linear criterion function was desired. Thus, it was decided to take an indirect approach to the problem of measurement; that is, to measure a variable that may be related to survival probability, but which is couched in terms more familiar to the pilot/decision-maker and which permits a linear criterion function.

A clue to the possible difficulty of measuring survival probabilities directly was provided during informal discussions with pilots in which they stated that they choose routes so as to minimize "exposure" to the enemy. It is unclear

what units were being used to measure "exposure", and it is also unclear what relationship was implied between "exposure" and the variables that describe a route selection situation. However, it is very clear that pilots can talk about "exposure" and the threat they feel from this exposure. In crisis situations they apparently do not consider survival or success explicitly. Rather, they implement intuition and training in reacting to a particular situation. Thus, they arrive at a course of action that they perceive as enhancing their chances for survival or for mission accomplishment.

We have, therefore, resorted to the use of a variable that we choose to call "perceived threat", which we would maintain is equivalent to the variable "exposure" alluded to by the pilot/decision-maker. As will be seen, it is possible to view the evaluation of a route alternative in terms of perceived threat as being equivalent to evaluation in terms of survival probability. However, instead of maximizing survival probability, the decision rule becomes minimization of perceived threat. Moreover, for reasons already cited, it is possible to directly ascertain the subjective quantity "perceived threat" whereas measurement of survival probability might be extremely difficult.

Now, there are many relationships between perceived threat and survival probability that could be hypothesized. However, it is not within the scope of the present research program to examine these hypotheses extensively. Instead, it is simply the intent that a relationship be chosen which meets the requirements stated earlier and whose validity could be tested if desired. As discussed below, both of these criteria are satisfied by the relationship that has been chosen.

Deferring for the moment any justification for the relationship, let

$$r_i = -\ln(P_i).$$

Then $\quad t_i = B \cdot r_i$

where B is a constant, P_i is the probability of survival as before, and t_i is the perceived threat of route alternative a_i. The decision rule is to select that alternative a_i, $i = 1, 2, \ldots$ which minimizes t_i.

At least five interesting observations may be made with respect to the transformation employed to obtain t_i. First, the transformation yields logically consistent results. As survival probability decreases perceived threat increases. Furthermore, perceived threat is zero when survival is considered certain. Second, if B were known, one could relate a value of t_i to the probability of survival. This observation suggests that a study could be conducted to test the hypothesized relationship although no plans presently exist for such a study. Thus, the desired quality of testable validity has been achieved.

Next, the decision rule has indeed been converted from one involving maximization of utility to one involving minimization of perceived threat. Furthermore, the process of threat minimization is equivalent to minimization of expected disutility.

Another observation is that a procedure to be discussed, which is used to represent the search for alternatives, produces a route that is actually a set of route segments connected so as to produce a continuous route. This immediately suggests that the utility function P_i can be expressed as the product of conditional survival probabilities that might be derived for each segment.

That is $P_i = \prod_{j \in R} p_{s_j}$

where p_{s_j} is the probability of survival on route segment j and R is the route under investigation. An algorithm employing P_i as the function to be maximized would then have a product as the criterion as stated earlier. However, through the transformation used to obtain t_i, the problem has been converted into one in which the criterion is a sum. That is, assuming $t_{s_j} = -B\ln(p_{s_j})$, then

$$t_i = \sum_{j \in R} t_{s_j}$$

where t_{s_j} is the perceived threat for a route segment and corresponds to p_{s_j}, and B is the constant defined previously. Thus, the transformation yields the desired linearity.

The final observation is that the use of a sum as the criterion with t_{s_j} as a component of the sum is similar to the procedure employed by Clark (1966) in his model of ground route selection. Clark referred to the terms of the sum as "tactical difficulties" and spoke of them as elements of an additive utility system. Unfortunately, development of Clark's model is incomplete (see page 12).

Exclusive of the appealing properties discussed above, some justification for the choice of the function relating t_i and P_i (or t_{s_j} and p_{s_j}) lies in the fact that under certain assumptions, the relation can be derived by applying principles that have served as a basis for many developments in classical psychophysics. That is, there may be historical justification for the chosen form of the relationship.

First of all, the underlying problem is actually a classical problem in psychophysics. There is measurable environmental information available in the form of various stimuli which relate to the uncertainty of survival. However, the pilots apparently react to a psychological sensation that they refer to as threat or exposure. The problem is to relate the environmental stimuli to the psychological sensation called threat.

The development starts with the "fundamental formula" (Rand, 1912) of classical psychophysics called Weber's Law:

$$\frac{\Delta S}{S} = C$$

where S is a physical measure of stimulus magnitude, ΔS is a small incremental change in S, and C is a constant difference in sensation resulting from the relative stimulus change. Based on classical theory, any function relating sensation to stimulus magnitude must satisfy Weber's Law.

Now, if the very critical assumption is made that the probability of survival P_i is in actuality a stimulus and if we let Ψ be a psychological sensation, then Weber's Law may be restated as

$$\Delta\Psi = \frac{K\Delta P_i}{P_i}$$

where $\Delta\Psi$ is the sensation increment resulting from ΔP_i and K is a constant of proportionality. The assumption that P_i is a stimulus is equivalent to the assumption that all the environmental stimuli relating to the uncertainty of survival have in some way been combined to produce P_i, and just this one stimulus is presented to the pilot.

Viewing the formula for $\triangle P_i$ as a differential equation, integration yields

$$\Psi = K \ln P_i + D$$

where D is a constant of integration. To evaluate D, one introduces the notion of threshold; i.e., that Ψ vanishes with some liminal value of P_i called p. Then, $D = -K \ln p$. Therefore,

$$\Psi = K (\ln P_i - \ln p)$$

or

$$\Psi = K \ln (P_i/p).$$

Since the scale of measurement is arbitrary, one may specify the liminal value of P_i as $p = 1$. This yields the final result

$$\Psi = K \ln (P_i)$$

which relates a stimulus to a sensation. In general, this relation is known as Fechner's Law. It can be seen that it is identical to the relation for t_i stated earlier if K is taken as -B. Also, the constant K (or B) may be experimentally determined. Thus, we have established the relation that was desired.

Now, a critical assumption in the above development may be stated as follows:

> Equally often noticed differences are equal, unless always noticed or never noticed. (See Luce and Edwards, 1958.)

This assumption means that all "just noticeable" threat situation differences ($\triangle P_i$) represent <u>constant differences</u> in sensation. Had the assumption been

that the just noticeable differences represent constant ratios in sensation; i.e.,

$$\frac{\Delta\Psi}{\Psi} = K\frac{\Delta P_i}{P_i}$$

then the result would have been much different. Such an assumption is made in the psychophysical theory developed by S. S. Stevens[3].

Representing the Search for Alternatives

One of the most challenging aspects of developing a model to describe the route planning task is the derivation of a method to predict the results of the process by which a pilot isolates candidate route alternatives in the first place. Attention is now directed to this task.

In accordance with pilot comments, the hypothesis is constructed that a helicopter pilot is mainly guided in his selection of a route alternative by his interpretation of intervisibility relationships that exist throughout the battlefield. In his search for alternative approaches to a target, the pilot first visualizes areas on the battlefield that are masked from the view of known or suspected enemy weapons. From this set of masked areas he is able to choose a series of areas whose proximity to one another is such that the series can be connected to form an avenue of approach. Once this avenue is determined, the route alternative can be finalized by selecting a series of route segments that follow the general shape of the approach corridor.

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3 For more discussion of the mathematical developments in the last few paragraphs, see Miller (1964).

In the vicinity of the target, the distribution of intervisibility areas is still important, since the pilot desires to conceal the details of his attack plan until the very last moment. Thus, he selects a route alternative leading to his firing point from among the masked areas in the vicinity of the target. Just prior to initiation of the firing sequence he climbs above the knap-of-the-earth[4] flight profile to achieve intervisibility and subsequently to conduct his attack.

Once the attack has been completed, he again selects a route that has characteristics similar to his approach route. In fact, the masked areas that formed his approach corridor may serve as his exit corridor. Protected route segments during the escape phase of the mission are as desired as were those selected during earlier portions of the mission.

The above conceptualization of the search for alternatives serves as inspiration for the procedure that has been adopted to represent the process in the descriptive route selection model. The procedure is an improvement over that offered by Clark (1966) in that it explicitly portrays the existence of areas over the battlefield through which the search for alternatives is more likely to be concentrated. It is also more readily comparable to the process that may actually be used by the decision maker.

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[4] Knap-of-the-earth flight is flight conducted at very low and almost constant altitude above the local terrain. Over wooded areas, sufficient elevation is used to clear the most prominent tree tops. Over open terrain, flight may be conducted at elevations below the height of trees in adjacent woods or tree lines.

Our procedure visualizes the boundaries of the various intervisibility areas as providing terminal positions for major segments of a route alternative. A major segment of a route alternative is defined to be one in which the intervisibility relationship that exists with all enemy weapons does not change. Thus, by definition, a major route segment extends from one boundary of an intervisibility area to another. Within a major segment, several minor segments may exist. These segments are differentiated from one another merely by changes in direction. They are included to permit shaping of the route alternative within an intervisibility area and result in a route that may follow the general shape of the intervisibility area.

To illustrate the procedure adopted to permit such a representation, we present the following example. Consider the line-of-sight map[5] of Figure 1. This map has been prepared for enemy weapons located at the positions marked (1) and (2) with the shaded areas being areas of intervisibility. Moreover, the route planning task is for an attack upon the weapon located at position (2).

Now, Figure 2 shows a simplification of the map of Figure 1. The various areas have been stylized with straight line segment boundaries. Moreover, each area has been coded to specify the intervisibility condition existing within

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[5] A line-of-sight map is a map prepared to show areas of a battlefield which are intervisible with the enemy weapons on the battlefield, given that the helicopter is flying a knap-of-the-earth flight profile. A procedure to prepare such a map is described in Appendix A.

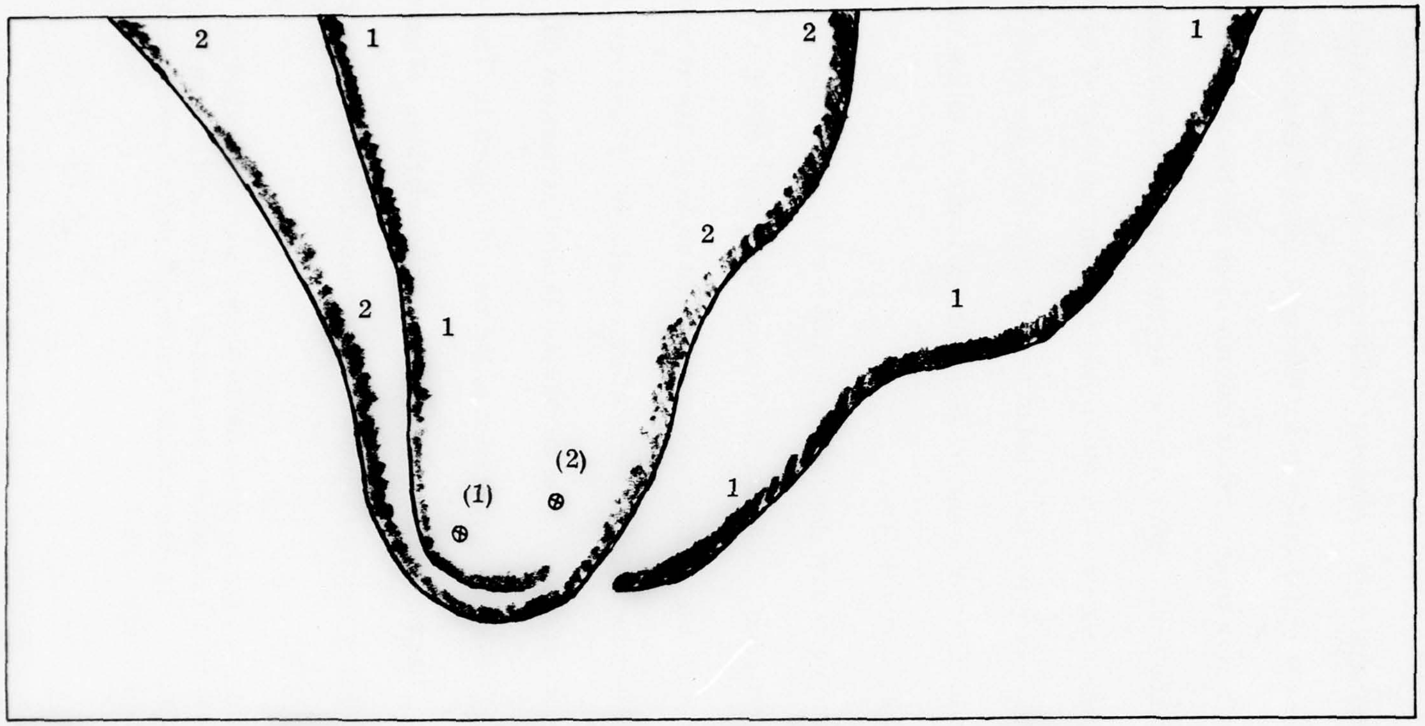

Figure 1.--A Line-of-Sight Map

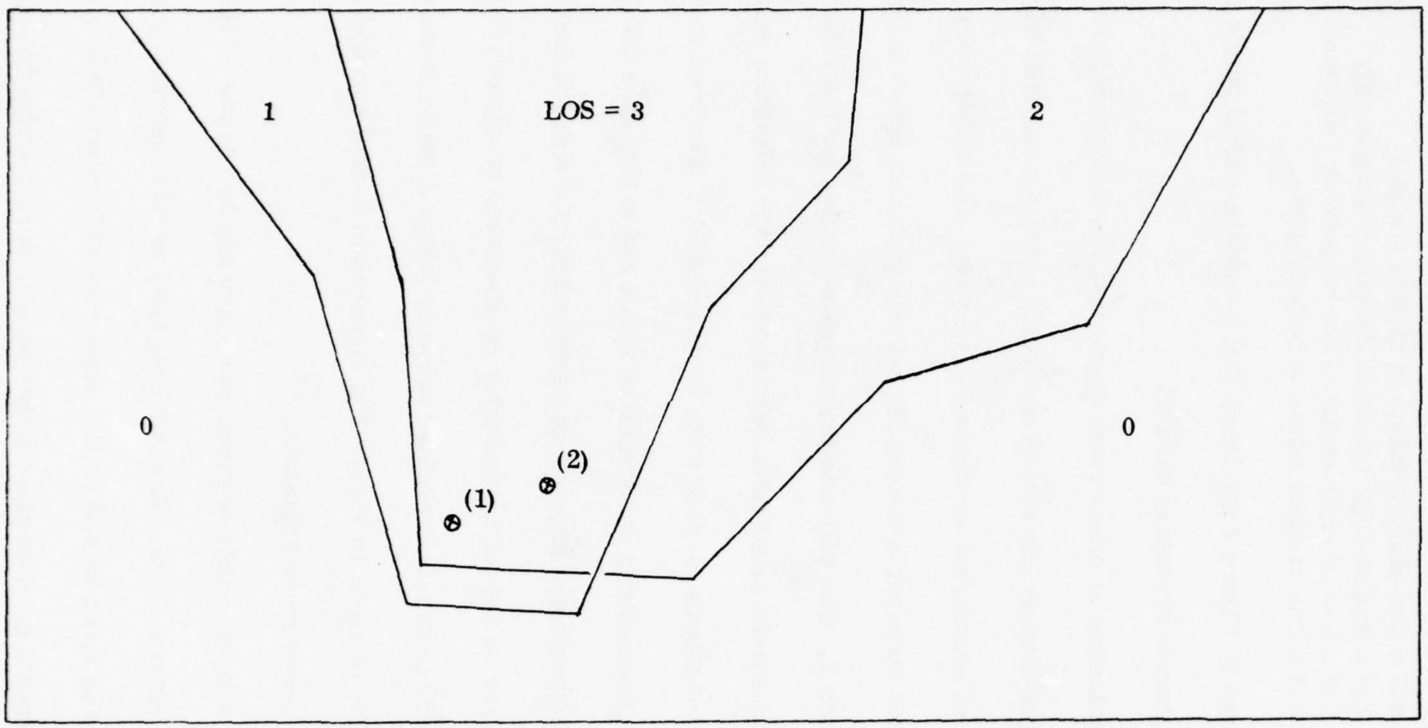

Figure 2.--A Stylized Line-of-Sight Map

its boundaries. The coding is as follows:

$$\text{LOS} = \begin{cases} 0 \text{ if a line of sight exists to neither weapon} \\ 1 \text{ if a line of sight exists to the target weapon only} \\ 2 \text{ if a line of sight exists to the supporting weapon only} \\ 3 \text{ if a line of sight exists to both weapons.} \end{cases}$$

The boundaries shown in Figure 2 are those that provide terminal points for the major route segments discussed earlier.

To permit selection of minor route segments, the irregularly shaped areas of Figure 2 are broken into sets of connected convex areas still having straight line segment boundaries as shown in Figure 3. The minor route segments will have their terminal points on the set of boundaries added to obtain Figure 3 from Figure 2. One will note that the same coding for intervisibility has been maintained and the areas have been numbered for reference purposes. Moreover, the line segments forming area boundaries have also been numbered. The number of line segments is designated as IMAX and in this case IMAX = 34.

Now, each minor route segment is represented as a straight line. Its terminal positions are on the area boundaries as discussed previously, and a series of these minor segments connected properly forms a major route segment. The convexity of areas in Figure 3 is required to permit straight lines to be used to form minor route segments.

In general, a minor route segment could join any two points on the boundaries of one of the convex areas. However, we have found it necessary to discretize the process in order to reduce the number of alternatives to a computable number. It should be remembered that we are merely trying to represent

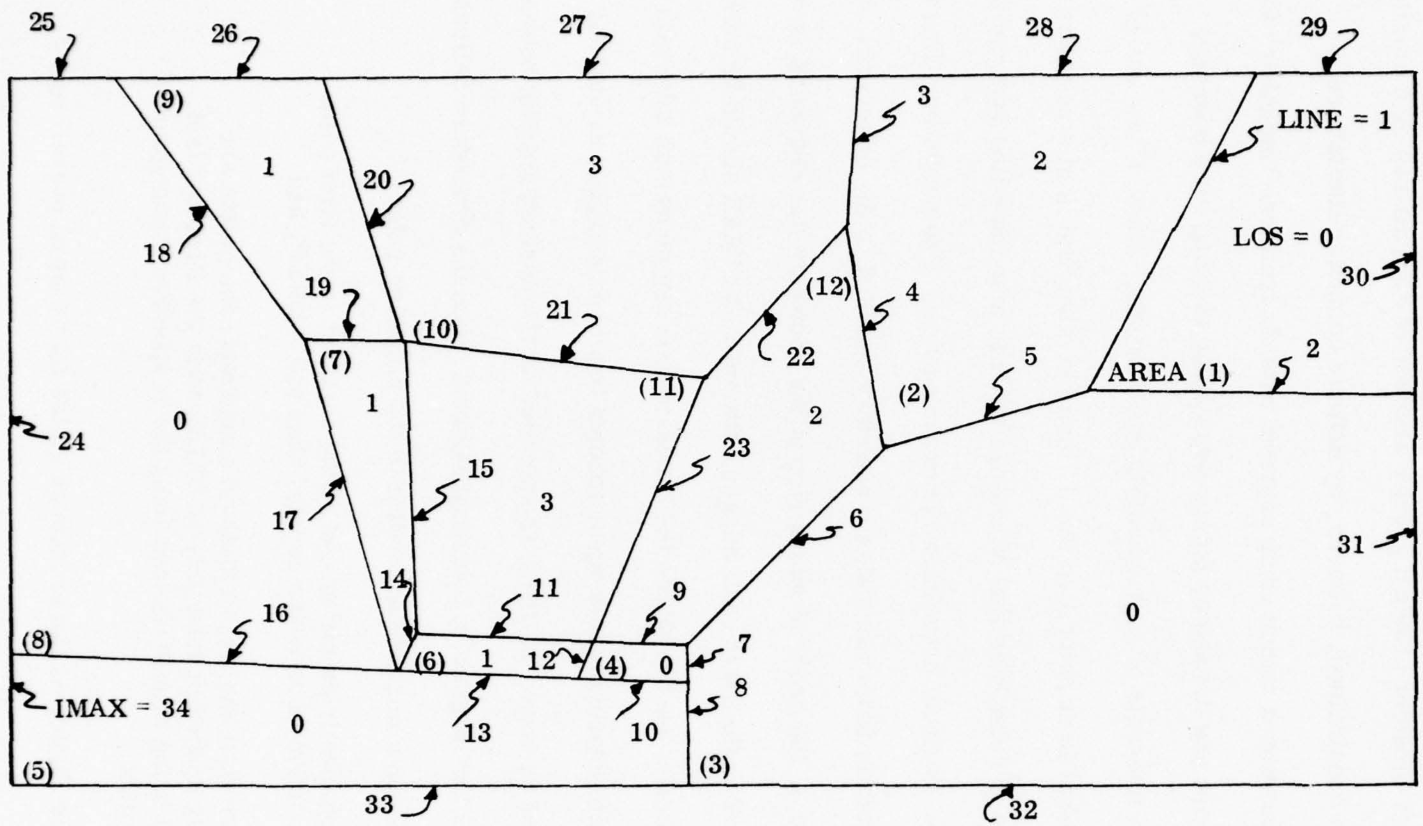

Figure 3.--Convex Area Representation

the process by which a search for alternatives is conducted. The decision-maker may in fact consider either a greater number of alternatives or a smaller number. We are constrained, however, by definite computer limitations.

In the procedure a minor route segment extends from one "neighbor" to another. Neighbors are defined as points obtained by dividing each boundary line segment into intervals of approximately equal length. Thus, if one end of a minor route segment is at point J on line I, then the other end is at a neighbor of I, J; that is, it is at point N on line M where line M is any other line that can be reached from line I without crossing an intervening line. The points on a line are numbered sequentially from one end of a boundary segment to the other end. As implied in Figure 3, the order of numbering of the boundary line segments is of no importance, other than that each integer between 1 and IMAX should be used.

The procedure used to divide the boundary line segments into intervals is designed to yield approximately equal spacing between neighbors around the entire boundary of an area. If DELP is specified as the desired spacing between points, and RD is the length of a boundary segment, then the procedure defines neighboring points on a segment according to the following rules:

a. the distance from either end of the segment to the first point on the segment is never greater than 0.9 · DELP, and

b. if more than one point exists on a segment, the points are equally spaced at intervals of DELP, with the first and last points being equally spaced from the respective line segment end points.

As may be seen in Figure 4, the procedure yields fairly equal overall spacing between points.

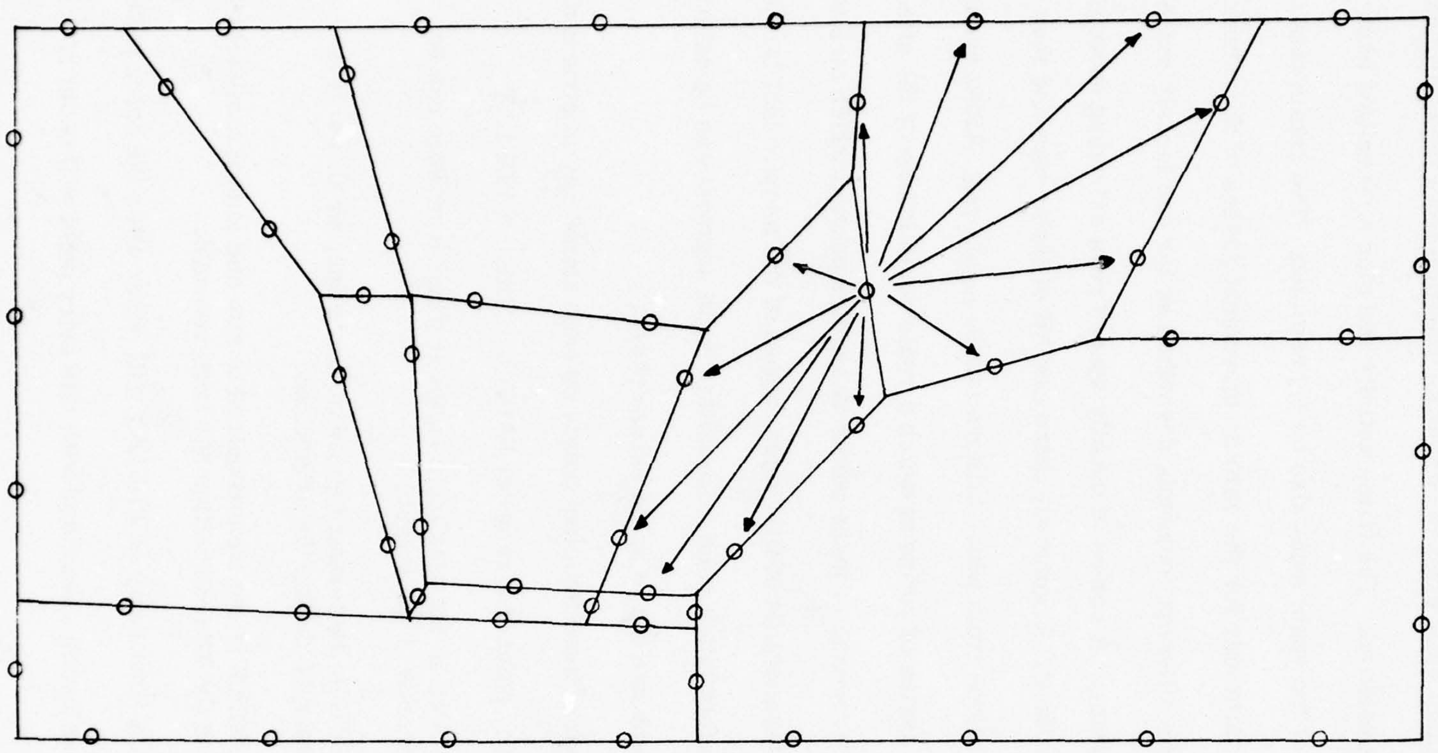

Figure 4.--Neighbors

So far, nothing has been said about the representation of an attack upon the target. A scheme must exist to permit a transition from the approach route into a firing position. The firing activity and then a transition back into the escape phase of the route must also be represented. The representation described so far is valid only for the enroute movement phases of the mission.

To solve the dilemma, concepts described so far are merely extended to cover the attack phase. A series of equally spaced rays extending outward from the target is visualized. In general, there are NR of these rays and they serve to define the directions from which attacks can be conducted. Along each ray are distributed a series of points at which a route could intersect the attack ray. Associated with each of these points is another point at which an attack can be broken at termination of fire (upon impact of the missile that has been launched). From this latter point a transition route segment can be selected to permit movement into the mission escape phase.

The procedure used to select points on each attack ray is structured to place the first entry point at a range of RMAXL + VHEL • TDELAY

where RMAXL is the maximum range at which a missile can be launched at the target,

VHEL is the forward speed of the helicopter that will be employed during the attack, and

TDELAY is the time required to aim and launch a missile once the attack position has been reached.

It is assumed that a time delay of TDELAY will occur after the entry point is reached so that the launch associated with this entry point will occur at a range

of RMAXL from the target. However, if this entry point is not within the boundaries of the battlefield, the range is shortened to place the entry point at the battlefield boundary.

After the first entry point on a ray has been selected, then succeeding points are placed on the ray at intervals of DELR (equivalent to DELP, but associated with attack rays) until one of two constraints terminate the procedure. The first constraint is that the launch range associated with a given entry point range must be greater than the minimum effective missile launch range RMINL. If R is the entry range, then

$$RLNCH = R - VHEL \cdot TDELAY$$

is the launch range.

The other constraint is that the exit point associated with a given entry point must lie outside the minimum approach range to the target RMAPP. The exit point is the position the helicopter would occupy at the time of missile impact, given that the missile was launched at the launch range RLNCH specified earlier. The approach range is

$$RAPP = RLNCH \cdot (1 - VHEL/VMIS)$$

where VMIS is the average flight velocity of the missile.

The reader should note that two different types of fire or modes of attack may be represented by the above procedure. Running fire (RF) is a mode of attack in which the helicopter continues to close on the target after a missile is launched (VHEL > 0). The firing run does not terminate until the missile impacts. Hover fire (HF) is a mode of attack in which the forward speed is

zero (VHEL = 0) during the flight of the missile. The helicopter essentially "pops-up" to a firing position, maintains the position while the missile is in flight and then "pops down" to commence the escape phase of the mission. In hover fire, the entry point, the launch point and the exit point are coincident.

The reader should also note that it is implied that the three points defining an attack (entry, launch, exit) lie on a straight line that emanates from the target and which is elevated sufficiently to provide a line of sight to the target from the entry point. The line represents the flight profile of the missile, and the implied relationship satisfies the requirement that the helicopter remain intervisible with the target in order that the missile might be guided to the target. As a simplification, it is assumed that the helicopter is intervisible with all enemy weapons on the battlefield during the entire attack. This includes transition to and from the firing run and the firing run itself. More will be said about this assumption in Chapter 4 and Chapter 5.

A completed picture of the final results of the procedure described so far is presented in Figure 5. To the neighbors shown in Figure 4 have been added the attack rays showing attack entry points (L) and attack exit points (E). A search for alternatives is conducted in this environment.

Now that we have described all the procedures used to specify the environment in which a search for alternatives is conducted, we may present the definitions of several different quantities that are required in the route selection procedure to be described. These quantities are all calculated as part of

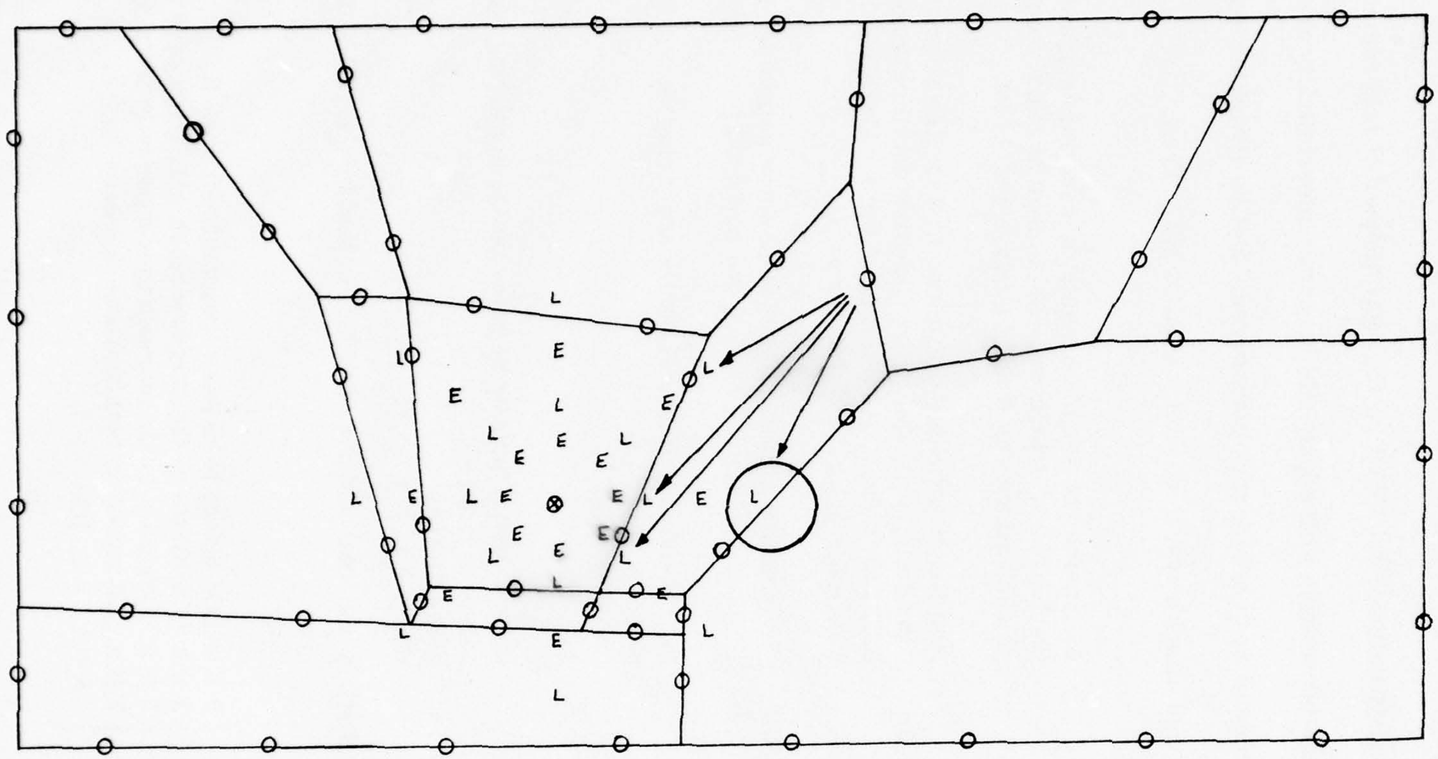

Figure 5.--The Complete Alternative Search Environment

the data preparation effort that must be accomplished before the route selection procedure can be applied to a given tactical scenario.

As previously defined, let IMAX be the total number of line segments used to specify the boundaries of the knap-of-the-earth intervisibility areas, and let NR be the number of attack rays considered. Define IM as the number of line segments and attack rays; i. e., IM = IMAX + NR. Then,

NPT(I) = the number of neighbor points on each line segment for I = 1, ... IMAX; or, the number of entry points on each attack ray for I = IMAX + 1, ... IM.

$\left.\begin{array}{l}\text{XLOCH(I, J)}\\ \text{YLOCH(I, J)}\end{array}\right\}$ = position coordinates of each point J on line segment I for I = 1, ..., IMAX: or, position coordinates of each exit point J on attack ray I for I = IMAX+1,... IM; where J = 1, ..., NPT(I) for all I.

$\left.\begin{array}{l}\text{XENTRY(I, J)}\\ \text{YENTRY(I, J)}\end{array}\right\}$ = position coordinates of each entry point J on attack ray I where I = 1, ..., NR and J = 1, ... NPT(I+IMAX)

JMAX = the maximum number of points appearing on any line segment or attack ray

$= \max_{1 \leq I \leq IM} \{NPT(I)\}$

J2MAX = the maximum number of entry points appearing on any attack ray; i. e.,

$\max_{IMAX+1 \leq I \leq IM} \{NPT(I)\}$

Finally, if NL is the total number of areas formed by the IMAX line segments, then

$$\text{LOS(K)} = \begin{cases} \text{0 if a LOS exists to neither weapon from area K,} \\ \text{1 if a LOS exists to the target weapon only from area K,} \\ \text{2 if a LOS exists to the supporting weapon only from area K,} \\ \text{3 if a LOS exists to both weapons for area K;} \\ \quad \text{K = 1, ..., NL.} \end{cases}$$

This coding is consistent with that presented earlier in the discussion of Figures 2 and 3.[6]

Several other quantities, not discussed so far, are required to facilitate the association of neighbor points and attack ray points with the intervisibility areas. No method of association has been given so far. First, define the coordinates of one end of a given line segment I as XL(I), YL(I) where I = 1,..., IMAX. Define the coordinates of the other end as XR(I), YR(I). Then

NFL(I) = the number of the intervisibility area that lies to the <u>left</u> of the line segment with origin at XL(I), YL(I)

NFR(I) = the number of the intervisibility area that lies to the <u>right</u> of the line segment with origin at XL(I), YL(I).

Note that the intervisibility conditions that exist on either side of line segment I can be determined by first finding L1 = NFL(I) and L2 = NFR(I) and by then finding LOS(L1) and LOS(L2). Note also that the same conditions exist for each neighbor point J on line segment I.

Following a similar procedure we define the variables NFRL(I,J), NFRR(I,J), MFRL(I,J) and MFRR(I,J). The first two of these variables specify the intervisibility areas that lie to the "left" and "right", respectively, of entry point J on attack ray I. The second two variables are associated in an

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[6] The research has never considered more than two enemy weapons simultaneously, so the coding for LOS(K) is general enough to meet the needs of the present research. In more general studies involving n weapons, a coding scheme permitting $\sum_{i=0}^{n} \binom{n}{i}$ distinct possibilities would be required.

identical way with exit points. Now, since we are dealing with points and not lines, the idea of direction from a point is really not applicable. However, for reasons to be explained, provisions are made for two intervisibility areas adjacent to each entry point and to each exit point. The "left" and "right" association is arbitrary. In fact the two areas may be the same. To facilitate understanding of this discussion the reader should consult Figure 5.

Within the small area that is circled in Figure 5, note that one of the attack entry points (L) lies extremely close to one of the intervisibility boundary line segments. In an approximation it seems unduly restrictive to consider the point as truly lying within just one area. If this procedure were adopted, then a route using L and approaching from the right would first have to pass through a neighbor on the boundary line segment adjacent to L. A more realistic route would be one in which L is approached directly, bypassing the line segment neighbor. Therefore, we allow each entry point and each exit point to be associated with as many as two intervisibility areas. In practice we have used a fifty meter distance from a line segment to differentiate whether a point is considered to be only within a single intervisibility area or to be lying on the area boundary. We have found in practice that a better route representation might have resulted had a greater separation been allowed. Also, an improvement might have been realized if more than two areas had been allowed. In some cases a point is extremely close to the intersection of three or more boundary line segments.

The Algorithm

A route is specified as starting at point JSTRT on intervisibility boundary line segment ISTRT. The route must terminate on one of the boundary segments NBOUND(I) where I = 1, . . ., NBD. Furthermore, the route must include one and only one attack. That is, exactly one of the route segments must pass from an attack ray entry point to its associated exit point. This fact is indicated if one of the route segment end points is a point I, J where I > IMAX. (The route selection procedure assumes attack rays numbered IMAX + 1, ..., IMAX + NR, and intervisibility boundaries numbered 1, ..., IMAX.)

Now, attention is directed to the procedure that has been developed to select a route having the characteristics specified above. One may note that there are a large number of alternative routes that could be structured to have the desired characteristics and which are composed of route segments defined according to the rules of the preceding section. The decision rule defined previously is used to identify that route alternative which should be selected. That is, we select the alternative a^* associated with

$$U^* = \min_i \{t_i\}$$

where t_i is the perceived threat of route alternative a_i, and the set $a = \{a_i\}$ contains all alternatives isolated by the alternative search procedure.

The reader should note that a route alternative a_i actually consists of N route segments $\{s_{i_j}\}$ where j = 1, 2, ..., N. Then, for alternative a_i

$$t_i = \sum_{j=1}^{N} t_{s_j}$$

where t_{s_j} is the perceived threat associated with segment j. This formulation is the result of the derivation of t_i from the subjective probability of survival P_i. However, the formulation also implies that we are assuming that the segments are utility independent and the utility of a route is a simple sum of the segment disutilities (Fishburn and Keeney, 1975), which we are. Justification of the assumption lies in the relation that is proposed to exist between P_i and t_i and the intuitive beliefs that: (1) a pilot would consider his chances for survival along one segment to be independent of those along another segment, and (2) an increase in perceived threat on one segment will always increase the route perceived threat. However our intuitive beliefs remain to be tested.

Now, one method of selecting a route would be to evaluate the threat represented by each route segment, and by enumeration, determine that route having the least threat. Such a procedure is completely infeasible for any but the simplest tactical situation representations. By far, a more efficient procedure is a dynamic programming technique first suggested by Jefferis and Fegley (1965) for routing problems and later modified by Clark (1966) to solve the armored vehicle route selection problem.

According to the procedure, optimal paths to various points in the matrix of neighbor points are recursively identified until a route path having all the required characteristics is identified. As each point in an optimal route is determined, the previous point in the route is identified, so that it is always possible to trace backward through a route at any stage to find a complete description of the route.

The dynamic programming algorithm is implemented through the construction of four sets U, V, S and T. The set U contains all points to which a route having minimum threat has been determined, given that the route does not contain an attack segment. Set S is similar to set U but it contains only those points to which a route having minimum threat has been determined, given that the route does include an attack segment. All the entry points to members of set U are also members of set U. Likewise, all the entry points to members of set S are also members of set S. This differentiation between sets U and S allows an escape route to retrace an approach route if necessary. Also, by convention, an attack entry point can appear only in set U since at the time an attack entry point is added to a route set, no attack segment is included in the route. However, the exit point associated with the attack entry point is added to set S since an attack segment is included in that route. Since the entry points to members of set S are also in set S, the attack entry point is both a member of set U and of set S. With this one exception sets U and S are disjoint. The convention is required to permit the construction of a complete route.

So far, we have discussed sets U and S which contain points to which optimal paths have been determined. The sets V and T contain points to which paths have been determined, but which have not been determined to be optimal. That is, paths to points in V and T are candidate optimal paths. If a path to a point in V is determined to be optimal, then the point is placed in set U, and since the path is known to be optimal, it is removed from set V. A similar relationship exists between sets S and T.

All neighbor points of each point in set U are contained in set V with the exception of neighbor points of an attack entry point as explained in a preceding paragraph. However, if a point that would normally appear in set V is also included in set U, it is deleted from set V since it is known that the path to that point is already optimal. One would not consider going from a member of set U to a neighbor for which an optimal route has already been determined. By definition, this new route to the neighbor would not be as good as that which had already been determined for the neighbor.

As stated, the set T is similar to set V as it contains the neighbors of points in set S. Again, a disjoint relationship is maintained between S and T for the same reasons cited above.

For each point in U, V, S and T, the total threat posed by the route taken to reach the point from the start point is recorded. Also, the entry point of the last segment leading to the member point is recorded. The following symbols may be used to clarify the discussion. Define:

$_{M,N}C_{I,J}$ = relative threat encountered in reaching (I, J) from the starting position (ISTRT, JSTRT), given that the route does not include an attack segment and that the entry point (M, N) appears in set U.

$_{M,N}D_{I,J}$ = relative threat encountered in reaching (I, J) from the starting position (ISTRT, JSTRT), given that the route does include an attack segment and that the entry point (M, N) appears in set S.

${}_{M,N}C^*_{I,J}$ = least threat obtainable in reaching (I, J) from the starting position, given that the route does not include an attack segment and that both point (I, J) and (M, N) are members of set U.

${}_{M,N}D^*_{I,J}$ = least threat obtainable in reaching (I, J) from the starting position, given that the route does include an attack segment and that both point (I, J) and (M, N) are members of set S. (The point (M, N) may be a member of both set S and set U if (M, N) is an attack entry point.)

DIJMN = threat encountered on the route segment from point (M, N) to point (I, J).

Then

$$ {}_{M,N}C_{I,J} = {}_{A,B}C^*_{M,N} + DIJMN $$

and

$$ {}_{M,N}D_{I,J} = {}_{A,B}D^*_{M,N} + DIJMN $$

where (A, B) is the entry point to (M, N) and is not equal to (M, N) or (I, J).

At a given stage of the dynamic programming algorithm, the last point (M, N) placed in set U or set S is selected as the point to be analyzed during the stage. First, (M, N) is considered as the entry point to each of its neighbors (I, J), and the quantities ${}_{M,N}C_{I,J}$ or ${}_{M,N}D_{I,J}$ are computed. Then, the points (I, J) are entered either in set V or set T, and the point (M, N) is recorded as the entry point for each of these new member points. Finally, a search is conducted to determine a point (P, R) to be placed either in set U or set S. The point (P, R) is removed either from set V or set T, it becomes the last entry in set U or set S, and the next stage of the procedure commences.

To determine (P, R), the quantities

$$VMIN = \min_{(I,J) \in V} \left\{ {}_{A,B}C_{I,J} \right\}$$

and

$$TMIN = \min_{(I,J) \in T} \left\{ {}_{A,B}D_{I,J} \right\}$$

are determined first, where (A,B) are entry points associated with the points (I, J) and, by definition, appear in set U or set V. Then, if VMIN < TMIN, (P, R) becomes the point (I, J) yielding VMIN. Otherwise (P, R) is the point (I, J) associated with TMIN. In the first case,

$$ {}_{E,F}C^{*}_{P,R} = VMIN$$

and in the second

$$ {}_{E,F}D^{*}_{P,R} = TMIN$$

where (E, F) is the entry point to (P, R).

The computer procedure to be described below uses V(I,J) to represent ${}_{M,N}C_{I,J}$, with the point (M, N) contained in the arrays IV (I,J) and JV(I,J). Likewise, T(I,J) represents ${}_{M,N}D_{I,J}$, with IT(I,J) and JT(I,J) containing the subscripts (M,N). The arrays U(I,J) and S(I,J) contain the quantities ${}_{M,N}C^{*}_{I,J}$ and ${}_{M,N}D^{*}_{I,J}$, respectively.

The steps in the computational process used to determine an optimal route are as follows:

1. Initialize the lists U,V,S,T,IV,JV,IT and JT to zero.

2. Initialize the route at the start point; i.e., set I = ISTRT and J = JSTRT. Also, record the fact that the optimal route to the initial point has been determined by setting U(I,J) to a small positive value (e.g., 10^{-5}). Record the fact that the route to I, J does not contain an attack segment by setting ESCAPE = .FALSE.

3. Determine the threat of the optimal route to the point (I,J) being analyzed; i.e., set

$$DU = \begin{cases} U(I,J) & \text{if ESCAPE = .FALSE.} \\ S(I,J) & \text{if ESCAPE = .TRUE.} \end{cases}$$

4. Determine the next neighbor point (M,N) to (I,J).[7] If all neighbor points have been analyzed, go to step 13. Otherwise, continue.

5. If the route to (I,J) includes an attack segment; i.e., if ESCAPE = .TRUE., go to step 12; otherwise, continue.

6. If an optimal route to (M,N) has already been determined; i.e., if U(M,N) > 0, go to step 4.

7. Determine the threat to be encountered in proceeding along the route segment between (I,J) and (M,N); i.e., determine DIJMN.

8. Compute the threat for a route to (M,N) that passes through (I,J); i.e., compute D = DU + DIJMN.

9. If a route to (M,N) has already been determined; i.e., if V(M,N) > 0, go to step 11; otherwise, continue.

10. Record the threat posed by the route to (M,N) that passes through (I,J); i.e., set V(M,N) = D. Also record the entry point to (M,N); i.e., set IV(M,N) = I and JV(M,N) = J. Then go to step 4.

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[7] The process used to successively determine neighbor points of (I,J) is discussed immediately following this description of the route selection computational procedure.

11. If a route passing through (I, J) to (M, N) would be better than the one already recorded for (M, N); i. e., if D < V(M, N), go to step 10; otherwise, go to step 4.

12. Perform steps 6 through 11 for a route that is known to contain an attack segment. Substitute S(M, N) for U(M, N); T(M, N) for V(M, N); IT(M, N) for IV(M, N) and JT(M, N) for JV(M, N).

13. Search all of list V for its minimum value; i. e., set

$$\text{VMIN} = \min_{\substack{\text{all I} \\ \text{and J}}} \{V(I,J);\ V(I,J) > 0\}$$

Record MS, NS as the values of I, J yielding VMIN.

14. Repeat step 13 to obtain TMIN from list T. Record MU, NU as the values of I, J yield[illegible] TMIN.

15. If the best route selected in steps 13 and 14 is one that contains an attack segment; i. e., if TMIN < VMIN, go to step 20; otherwise, continue.

16. Record the threat of the optimal path to MS, NS; i. e., set U(MS, NS) = VMIN. Set V(MS, NS) = 0 to maintain disjoint sets and set I = MS and J = NS as the next point to be analyzed by the procedure.

17. If MS, NS is an entry point of an attack segment; i. e., if MS > IMAX, go to step 19; otherwise, continue.

18. Set ESCAPE = .FALSE. to indicate that the new route does not contain an attack segment and go to step 4.

19. Set ESCAPE = .TRUE. to indicate that the route now contains an attack segment. Also record the threat posed by the route in the set reserved for routes containing attack segments; i. e., set S(MS, NS) = VMIN; go to step 4.

20. Record the threat of the optimal path to MU, NU; i. e., set S(MU, NU) = TMIN. Set T(MU, NU) = 0 to maintain disjoint sets and set I = MU and J = NU as the next point to be analyzed by the procedure.

21. If MU, NU is on one of the terminal boundaries of the route; i.e., if MU = NBOUND(K), K = 1, . . . , NBD, go to step 22; otherwise, set ESCAPE = .TRUE. and go to step 4.

22. The route is complete. Trace backward through the route using IT, JT, IV and JV to locate all the points comprising the route. The position coordinates of all route points except the attack segment entry point are given by the arrays XLOCH, YLOCH. The attack entry point position is found in the arrays XENTRY, YENTRY.

The procedure outlined above uses two internal procedures that are very important and they must be discussed. The procedure used to determine a route segment threat DIJMN is so important its discussion is deferred until the next chapter. However, the procedure for mechanizing the search for neighbor points is discussed in the following paragraphs.

The procedure used to search for neighbor points (M, N) to a given route analysis point (I, J) is designed so that the last neighbor point it determined is input, and it then determines the next neighbor point. The procedure is programmed as a subroutine to be called by the route selection computer program as needed. The procedure is initialized by providing (I, J) as input. When all neighbors of (I, J) have been determined, then (I, J) will be returned. This fact is used to terminate the search for neighbors.

Now, if (I, J) is a point on one of the intervisibility area boundaries (I $\leq$ IMAX) and if a route that does not include an attack segment is being analyzed (ESCAPE = .FALSE.) then the procedure searches all points on all intervisibility line segments and all attack entry points for the neighbors of (I, J). The search is conducted by first incrementing J on line I until all points on line I have been analyzed. Then I is incremented and J is reinitialized at

one. When all I have been examined, I is reinitialized at one and the procedure is continued until the original I,J combination is again achieved. To be a neighbor of (I,J), the point (M,N) must satisfy one of the following sets of relationships

$$\left.\begin{array}{r}\mathrm{NFL(I) = NFL(M)}\\ \mathrm{or\ NFL(I) = NFR(M)}\\ \mathrm{or\ NFR(I) = NFL(M)}\\ \mathrm{or\ NFR(I) = NFR(M)}\end{array}\right\}\ \text{if } M \leq \mathrm{IMAX}$$

or

$$\left.\begin{array}{r}\mathrm{NFL(I) = NFRL(M,N)}\\ \mathrm{or\ NFL(I) = NFRR(M,N)}\\ \mathrm{or\ NRF(I) = NFRL(M,N)}\\ \mathrm{or\ NFR(I) = NFRR(M,N)}\end{array}\right\}\ \text{if } M > \mathrm{IMAX}$$

The first set of relations is valid when M is not an attack ray and the second set is valid when M is an attack ray. The quantities used were described on page 51 of this chapter and identify the intervisibility areas adjacent to a point.

If (I,J) is a point as above, but the route already contains an attack segment; i.e., if ESCAPE = .TRUE., then the search for neighbors is conducted in the same order described above, but attack entry points are excluded since only one attack is permitted per route. Therefore, no neighbors with M > IMAX are considered. Consequently, the second set of relations above is not required.

If (I,J) is an attack exit point then the procedure is similar to that described above for the case when ESCAPE = .TRUE., since this is the case here. However, the order of search is somewhat altered since it is unnecessary to increment J on the original line segment I. Only one point per attack ray is considered by definition. Instead, I and J are immediately reinitialized to one to begin the search for neighbors among the intervisibility boundary line segments.

CHAPTER 3

PHASE I EXPERIMENTATION

by Don C. Hutcherson

Introduction

In Chapter 2 a model was derived to predict the decision-making behavior of helicopter pilots in a route planning task. It was proposed that a pilot selects a route plan in such a way as to minimize "exposure" to the enemy, and to represent this mode of behavior, the concept of "perceived threat" was introduced. This concept was used in the decision rule as follows:

> From a set of alternative route plans, select as the plan to be followed that which possesses the least perceived threat.

The procedure employed for constructing route alternatives produces routes that consist of a series of connected straight-line segments. Thus, the perceived threat of a route alternative is actually some function of the perceived threats possessed by each of the segments within the route. Assuming utility independence and incremental increases in threat always increase route threat (Fishburn and Keeney, 1975), a linear function was proposed. That is, if t_i is the perceived threat of alternative a_i, then

$$t_i = \left\{ \sum_{j=1}^{N_i} t_{s_j} \right.$$

where t_{s_j} is the perceived threat of segment j, and N_i is the number of segments comprising alternative a_i.

The most demanding task of the research program came after the decision model had been derived, for it was then necessary to develop procedures to be used in validating the model. As outlined in Chapter 1, the validation effort actually was comprised of two experiments. The first, known as the Phase I Experiment was designed to gather data for the model. The second, known as the Phase II Experiment, was designed to test the predictive qualities of the model based on data collected during Phase I. In this chapter, attention is directed to a comprehensive description of the Phase I Experiment and results obtained at Ft. Rucker.

One of the first and most critical research tasks associated with Phase I was development of methods for eliciting values of t_{s_j} from individual decision makers. Without this capability it would have been impossible to use the route planning model to predict routes for those decision makers and, hence, to validate the model. The task was made even more difficult by the fact that very little was known about the way in which a decision maker actually views the relationship between t_{s_j} and all the situation variables associated with route segment j. Therefore, not only was a procedure for measurement required, but also a model (or models) of perception was needed.

The second major task associated with Phase I was development of an experimental design to be used in gathering data. The design had to yield the required information efficiently, for the experiment was to be conducted with human subjects, and it was desired that subject fatigue not become a factor in the experiment.

The next Phase I research task consisted of locating a suitable subject group and of conducting the required experiment. Since it was desired that qualified decision-makers be used as subjects, the search was limited to Army helicopter pilots with combat experience. With this limitation it was considered most convenient to conduct the experiment at an Army installation at which a large population of prospective subjects might be found.

The final Phase I research task was associated with analysis of data gathered during the experiment. During this task, data for the Phase II Experiment were developed, and some preliminary conclusions about the decision-making behavior of pilots were formulated.

In this chapter, all the topics discussed above will be described at length. First, a short discussion is presented in which pertinent route selection situation variables are identified. This discussion will also show how a decision-maker might relate perceived threat to these variables. Then, since it is unknown how a decision-maker views the relationship in an actual route planning task, three models are proposed to represent a spectrum of anticipated behavior. Next, the experimental design developed to gather the appropriate data is discussed, and is followed by a description of measurement procedures used to gather the required data from decision-makers. Finally, selection of the subject group, conduct of the experiment and analysis of the results are presented as separate topics.

Situation Variables

We presume that the threat a pilot feels as he traverses a given route segment may first be a function of whether or not he is exposed to an enemy weapon. The perceived threat is probably much lower for an unexposed route segment.

Given that a segment is exposed, the perceived threat may then be a function of factors related to the physical characteristics of the intervisible enemy weapon and of the helicopter, and to the variables describing the spatial orientation of the helicopter relative to the enemy weapon. To be more explicit, the intensity of the threat might be described as a function of at least the following:

1. the pilot's assessment of the volume of fire of which the weapon is capable;

2. the pilot's assessment of the lethality of accurately aimed fire from the weapon; and

3. the pilot's assessment of the accuracy with which fire may be delivered.

All three of the above characteristics are properties of the opposing weapon system. However, the latter two are, to an extent, controllable by the pilot. For example, both lethality and accuracy are functions of the range to the opposing weapon and the orientation of the helicopter relative to the weapon. Thus, the pilot can affect lethality and accuracy by his choice of a route in relation to the enemy's position.

To better understand the above discussion, let us specify the geometry of a threat evaluation situation as in Figure 6. The segment is of length D and its midpoint is separated from an enemy weapon by a distance R. Furthermore, the helicopter is heading at an angle ϕ relative to the weapon. If the helicopter is proceeding at a speed V, then the exposure time while traversing the segment is $T = D/V$.

The perceived accuracy of enemy fire may be a complex function of V and of all the geometric variables shown in Figure 6. In general, increasing range might tend to reduce perceived accuracy, increased exposure time might tend to increase perceived accuracy, and changes in ϕ might affect perceived accuracy by changing the profile presented to the weapon. Perceived weapon lethality might also be partially a function of range and of ϕ. Therefore, from all previous discussions, it is presumed that the following quantitative and qualitative situation variables are important enough to be considered in the analysis:

Quantitative:

- R - range to enemy weapon
- T - exposure time
- ϕ - relative heading angle
- V - helicopter speed

Qualitative:

- C_S - pilot self confidence
- C_H - pilot confidence in his vehicle
- W - enemy weapon type.

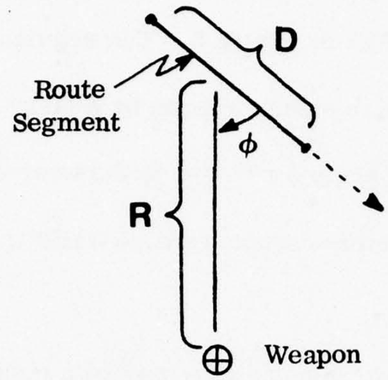

Figure 6.--Threat Evaluation Situation

Now, the effects of factors C_S, C_H, and V are lumped into one effect which is called the subject effect. The factor that produces this effect is defined as S and serves as a representation of differences among pilots. In the research program it has not been deemed necessary to study the effects of C_H and C_S individually. Instead, the overall subject effect S is considered to be the important variable. However, it has been our experience that helicopter pilots are, in general, accustomed to operating a particular type of vehicle in a given mission situation. Therefore, during experimentation, the C_H effect becomes confounded with the C_S effect anyway. Finally, the speed V with which a route segment will be traversed is partially a personal choice. However, it also is a property of the vehicle type which the pilot implicitly assumes himself to be flying in a given mission context. Therefore, the effect of V can be (and is) lumped in the total effect of S. Hence, the final set of situation variables is R, T, ϕ, S, and W.

Perceived Threat Models

In the previous section, commentary was offered on how a decision-maker might view the relationship between perceived threat and the situation variables discussed. However, very little is known about the decision-maker's actual mode of thought. The arguments used were intuitive and are certainly subject to error. Therefore, in the absence of more information, three models of the relationship are proposed. While the exact form of each model is to an extent arbitrary, the models are intended to cover a wide spectrum of possible behavior. The experimentation plan discussed in Chapter 4 has been designed in such a way that the model or models that are most representative of individual pilot decision behavior in an actual route planning task can be isolated.

The first model is known as Model One. It is intended to be representative of a class of perception models which are almost insensitive to differences among individual pilots. Simply stated, the threat perceived by a pilot on a route segment is predicted by the relation:

$$t_s = \begin{cases} N \cdot T \text{ if the segment is exposed to N enemy weapons} \\ .001 \cdot T \text{ if the segment is unexposed} \end{cases}$$

where T is the travel time for a given route segment. Note that the model is sensitive to individual variance only because different pilots select different speeds with which to traverse a path. Note also that for simplicity the model assumes additive disutilities with respect to exposure to multiple enemy weapons.

In several ways, Model One represents conservative decision making. First, exposure to even one enemy weapon for a given period of time is predicted to be perceived as much more threatening than non-exposure for the same period. The factor of one-thousand has been assumed arbitrarily in Model One to account for this type of conservatism. Second, no matter what the range to a weapon is, the weapon is still considered as threatening as any other weapon. Finally, all weapons regardless of their characteristics are considered equally threatening.

In other ways, the decision behavior is not so conservative. Note that among equally exposed route segments (including non-exposed route segments), Model one predicts that a pilot will select the shortest route. This prediction is made without regard to the range or the orientation of the segment with respect to any of the weapons to which the route might be exposed. Thus, a short exposed segment passing very close to any enemy weapon would be chosen over a longer exposed segment that is more distant from the weapon. Such behavior fails to account for the fact that the weapon might be considerably more lethal at close range. Also, the model does not account for the fact that some weapons are more accurate if fired from the helicopter's side aspect while others are more accurate from the rear. Nevertheless, since protected route segments are favored so strongly in comparison to exposed segments, the model does represent conservative behavior. In fact, the model may very well be representative of many types of decision makers.

Experimentation required to gather input data for the model consists merely of determining what speeds a particular helicopter pilot will employ during different phases of his mission. Since the model is so insensitive to individual behavior, one might view the model as one to be used in the absence of any information regarding individual pilot decision behavior.

The next model down on the scale of conservatism and up on the scale of sensitivity is a model that is known as Model Three.[1] This model states that the threat percieved by a pilot on a route segment can be predicted by the relation

$$t_s = \begin{cases} T \cdot \sum_{i=1}^{N} \delta_i C_i & \text{if the segment is exposed to at least one enemy weapon} \\ .001 \cdot T & \text{if the segment is unexposed} \end{cases}$$

where

$$\delta_i = \begin{cases} 1 & \text{if the midpoint of the route segment is within the effective firing range of enemy weapon i and is exposed to weapon i} \\ 0 & \text{if otherwise.} \end{cases}$$

C_i = the relative threat of weapon i with respect to the weapon type being attacked

N = total number of enemy weapons considered in the tactical scenario.

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[1]Model Two was dropped during experimentation when it was found that it produced results that were almost always identical to those produced by Model One.

Again, the exact form of the relation is somewhat arbitrary. It is intended merely to reflect a relaxation in conservatism and a higher degree of sensitivity to differences between individual pilots. For simplicity, additive disutilities is again assumed with respect to exposure to multiple enemy weapons. Also, the relative threats of enemy weapons (C_i) and the maximum effective range of enemy weapons are quantities to be determined from individual pilots. They are subjective estimates as opposed to quantitative weapon performance estimates. Finally, the perceived threat of weapon i is measured relative to the perceived threat of the target weapon type which is scaled to one. Thus, this model would yield the same results as Model One if the maximum effective range of all enemy weapons were judged to be infinite and if $C_1 = C_2 = \ldots = C_N = 1$.

Model Three is less conservative than Model One in that enemy weapons are considered threatening only if the route segment is perceived to be within range of the weapons. Furthermore, the existence of perceived differences between weapons is acknowledged--not all weapons are considered equally threatening. The model still does not recognize the effects that orientation of a route segment with respect to a given enemy weapon might have on the perceived threat; nor does the model recognize variations of perceived threat as a function of range within the maximum effective range perceived for a given weapon. The ramifications of these model properties were outlined earlier in the discussion of Model One.

The model is more sensitive to variations in individual behavior because the relative threats of enemy weapons (C_i) and the maximum effective range of weapons are subjective estimates as opposed to quantitative estimates. Thus, to use this model, procedures must be developed to elicit range and threat information from actual decision makers. When Model Three is used to predict t_s, the routes selected by the model derived in Chapter 2 become more a property of an individual pilot.

The final model, or Acid Test Model, derives its name from the fact that it is associated with the most detailed and complex representation of pilot behavior considered. It is the most sensitive of the three models to individual decision-maker behavior. As it turns out, it also represents the least conservative behavior of the three models. Routes selected using this model to predict route segment threat can be associated with very aggressive pilot performance.

The Acid Test Model represents behavior corresponding to that proposed in the preceding section. Thus, it predicts route segment threat perception with the following relation

$$t_s = \begin{cases} \sum_{i=1}^{N} \delta_i \cdot D_i(R, \phi, T) & \text{if the segment is exposed to at least one enemy weapon} \\ F(T) & \text{if the segment is unexposed} \end{cases}$$

where

$$\delta_i = \begin{cases} 1 & \text{if weapon } i \text{ is intervisible with the midpoint of the route segment} \\ 0 & \text{if otherwise} \end{cases}$$

R = range to the enemy weapon from the segment midpoint

ϕ = included angle between the segment heading vector and a vector to the target from the segment midpoint

T = travel time on the segment

N = total number of weapons considered in the tactical scenario

$D_i(R, \phi, T)$ = empirically determined function of R, ϕ, and T, relating threat of the segment to weapon i

$F(T)$ = empirically determined function relating unexposed travel time to perceived segment threat.

The reader should note that the functions $F(T)$ and $D_i(R, \phi, T)$ are actually decision-maker opinions. Thus, the model is subjectively based in its entirety. As related in a following section, the procedures developed to elicit these decision-maker opinions give rise to a major experimentation effort. Furthermore, analysis of data reveals that $D_i(R, \phi, T)$ is very much the property of an individual decision-maker. However, it is determined that the magnitude of the range of $F(T)$ in relation to the range of $D_i(R, \phi, T)$ allows one to use practically any small-valued positive function for $F(T)$.

Additivity Implications

The reader will recall from Chapter 2 that an assumption basic to the entire route selection model is that additive disutilities exist for segments of a route (with respect to perceived threat). To test this assumption one would have to know how a decision-maker actually perceives threat as indicated by his performance in a route planning task. However, the three threat perception models that have been proposed simply describe possible

modes of behavior. Thus, the assumption cannot be tested in the Phase I Experiment. Nevertheless, an interesting question still exists. If a decision-maker actually did perceive threat as described by one of the three models, what would be the implications insofar as the additivity assumption is concerned?

With certain restrictions,[2] if a decision-maker perceives threat according to Model One or according to Model Three, then the assumption of additive segment disutilities is satisfied. This is so because perceived threat is a simple linear function of T only. However, if a decision-maker actually perceived threat according to the Acid Test Model, then it is highly unlikely that the assumption would be valid since very special forms of the function $D_i(R, \phi, T)$ would be required. For example, if $D_i(R, \phi, T)$ were invariant in R and ϕ but non-linear in T, the assumption would be violated. Of course, if the function were also linear in T, then Model One would result and the assumption would be satisfied.

Thus, one of the purposes of the Phase I Experiment was to determine whether or not additive segment disutilities could be assumed for a route, given that a decision-maker actually does perceive threat according to the Acid Test Model. Such independence would be expected if the decision-maker actually considers his conditional probability of survival on any segment to be independent of that on the other segments, and if the relationship between this survival probability and perceived threat is in fact that proposed in Chapter 2.

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[2]Discussed in Chapters 4 and 7.

As will be seen in the analysis section of this chapter, no special data had to be collected for the test of independence.

Experimental Design

The design developed for the Phase I Experiment had to be extensive enough to gather data required by each of the perceived threat models described earlier in this chapter. Moreover, data were desired to check some of the assumptions of the route selection model in general and of the perceived threat models in particular. Thus, the experiment was designed to yield the following data for each decision-maker:

1. the type of helicopter normally flown during an attack;

2. the speed normally employed while conducting knap-of-the-earth flight as well as a range of variation in this speed;

3. the speed normally employed while conducting a running-fire attack as well as a description of how speed might vary during an attack;

4. the overall relative threat perceived for each of several different types of enemy weapons;

5. the maximum effective range perceived for each of several different types of weapons;

6. an estimate of the function $D_i(R, \phi, T)$ for each of several different types of weapons; and

7. an estimate of the function $F(T)$.

As can be seen, the amount of information to be gathered from each subject was quite large. Therefore, the design for the Phase I Experiment had to be efficient to avoid subject fatigue.

As discussed in the next section, direct interrogation methods were employed to obtain all of the data outlined above. Thus, the only data for which particularly interesting experimental designs were required are the data used in estimating $D_i(R, \phi, T)$ and $F(T)$. A discussion of the design for $D_i(R, \phi, T)$ will be presented first.

<u>$D_i(R, \phi, T)$.</u> The function $D_i(R, \phi, T)$ has been assumed explicitly to be dependent upon the route segment exposure time (T), the heading of the helicopter relative to the enemy weapon (ϕ), the distance from the route segment mid-point to the enemy weapon (R), and the type of enemy weapon being considered (i). In addition, it has been stated that each pilot or subject might be unique in his assessment of enemy threat. Thus, it is assumed that $D_i(R, \phi, T)$ is also a function of the subject to whom a given $D_i(R, \phi, T)$ belongs. Finally, it is assumed that an experiment conducted to determine $D_i(R, \phi, T)$ for a given subject would yield data from which only an estimate of the function could be obtained since each observation might possibly be in error. Specifically, it is assumed that the jth response obtained from a given subject and corresponding to a particular set of values for i, R, ϕ, and T can be expressed as

$$O_j = D_i(R, \phi, T) + \epsilon_j$$

where O_j is the reponse obtained and ϵ_j is the error in the response. Moreover, ϵ_j is assumed normally and independently distributed with zero mean and variance σ^2.

Now, aside from the above assumptions, very little was initially known about the function $D_i(R, \phi, T)$ that could be used to guide the development of an experimental design. It was suspected that the function might have a very complex shape, and that it might vary considerably from one subject to another. Furthermore, it was known that a fairly complete description of the function would be required for each subject since the description would be used as input data for the route planning model. Finally, it was desired that the experiment should yield a statistically accurate and precise estimate of the function.

From these considerations, it was decided to conduct a factorial experiment that would comprehend a wide variation in each of the factors i, R, ϕ and T for each subject participating in the experiment. However, consideration of the relatively large set of independent variables necessitated a very cautious selection of the number of levels of each factor. Moreover, even with comparatively straightforward techniques for eliciting responses at each combination of factor levels, subject fatigue was contemplated as becoming a possible problem. Therefore, the design allowed for only one replication of the factorial for each subject. Thus, the design was a $(w)x(t)x(r)x(p)$ factorial with one replication per subject where

w = number of levels of enemy weapon factor,

t = number of levels of the route segment exposure time factor,

r = number of levels of the separation range factor, and

p = number of levels of the relative heading factor.

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THE HELICOPTER ROUTE SELECTION MODEL (DYNFLITE).(U)
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UNCLASSIFIED RF-2978-FR-76-4(0) NL

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Now, for purposes of analysis, there was actually a fifth factor in the experiment to account for the assumption stated previously that each subject might be unique in his assessment of $D_i(R, \phi, T)$. This factor is called the subject factor and was measured at s levels, where s is the number of subjects that participated in the experiment. Thus, the overall design was actually a (s)x(w)x(t)x(r)x(p) factorial with one replication. Another approach would have been to assume that there was no subject effect. Had this assumption been adopted, then the design could have been viewed as a (w)x(t)x(r)x(p) factorial with s replications, and the precision of estimates obtained from the experiment would have been controllable through the parameter s. However, the assumption of no subject effect was viewed as being unduly restrictive. It was considered desirable that tests for the existence of a subject effect be conducted. Then, if such tests proved negative, the alternative model still could be adopted.

After the basic design was formulated, attention was directed to an analysis of each factor in the experiment to determine the number of levels to be considered, whether the factor should be treated as quantitative or qualitative, and whether the effect associated with each factor should be treated as fixed or random. The analysis began with the subject factor s.

The subject factor was obviously a qualitative factor, but at the time the design was being formulated, the number of subjects that would be available for the experiment was unknown. However, as it turned out, eight subjects participated. Thus, the subject factor was measured at eight levels. In addition, steps were taken to assure that the subject effect could be treated as a random effect.

Selection of w was guided by a desire to obtain information across a representative cross section of enemy antiaircraft weapons that might be encountered by helicopters in a forward area during a mid-intensity war. A review of various classified military intelligence documents revealed that this objective could be achieved by considering three types of weapons. Thus, the qualitative factor W was measured at three levels and was considered to produce a fixed effect.

The weapons selected were: (1) the 14.5 mm light antiaircraft weapon system employing a manual sighting mechanism; (2) the 23 mm light antiaircraft weapon system employing a radar directed firing system; and (3) the REDEYE heat seeking guided missile system launched by a dismounted two man crew. All weapons are highly mobile and are employed in forward areas. The 14.5 mm weapon is considered to be among the lightest antiaircraft weapons that might be encountered by low level aircraft such as helicopters while the other two weapons might be among the heaviest to be encountered.

Selection of the levels of the remaining factors T, R and ϕ was guided by a desire to determine an "adequate" definition of the response surface for each weapon and subject. This meant that the levels selected should cover the expected range of variation of each factor, and that enough levels of each factor should be selected to provide an indication of the shape of the surface as a function of each factor. However, the number of levels of each factor that could be used was necessarily limited by the endurance of the subjects and the time available for the experiment. Thus it was decided to use a minimum of

three levels and a maximum of five levels as explained in the following paragraphs. With a minimum of three levels available for each factor it was reasoned that an estimate of up to a quadratic effect would always be available for any one of the three factors, and this was considered to provide an "adequate" definition of the response surface.

Selection of the levels of T was guided by a desire to cover the range of exposure times that might be encountered while traversing a single route segment of the type discussed in Chapter 2. Therefore, an analysis of representative route selection maps of the type shown in Figure 5, Chapter 2 was conducted. It was found that 45 seconds would be a suitable upper limit on T. It was also decided, arbitrarily, that the minimum number of levels (three) discussed above would be sufficient. Thus, the quant[illegible] factor T was considered to be a fixed effect at three levels. The levels chosen were 5, 15, and 45 seconds. A fourth level of T at zero seconds was implied. However, at this level, subjects would presumably feel no threat, hence the response surface would collapse to zero. Therefore, zero was not employed as a level of T.

Selection of levels of R was guided by a desire to cover the range of separation distances for which a decision maker might feel threatened. One value most certainly is the value zero. Indeed, a decision maker might feel most threatened in passing directly over a weapon. The other value is the distance at which the perceived threat first falls to zero. However, this distance was unknown at the time that the experiment was being designed. Furthermore, it was anticipated that this zero threat range would be a function of the

subject, the weapon type and the exposure time, and might even be a function of relative heading. Thus, the zero threat range could not be used directly as a factor level in the perceived threat experiment.

To solve the above dilemma, it was decided simply to select three evenly spaced levels of R that would probably fall within the zero threat range but still cover most of the range of separation distances for which a decision maker might feel threatened. It was decided also that a separate experiment should be designed to obtain zero threat range data. By adopting this approach, it was reasoned that the minimum acceptable degree of surface definition discussed above would be achieved. Moreover, the zero threat range data would be available to provide a more complete description of the response surface as a function of R. Hence, in the perceived threat experiment, R was considered a quantitative factor measured at three levels yielding a fixed effect. The three levels were specified as follows:

1. a separation of zero meters;
2. a separation that is approximately 40% of the estimated effective range of the weapon as published in weapon documentation; and
3. a separation that is approximately 80% of the published effective range.

The experimental design used to obtain zero threat range data will be discussed in a paragraph to follow.

The final factor ϕ was considered to produce a fixed effect measured at five levels, starting at zero and separated by 45 degrees (0, 45, 90, 135, 180).

This range of variation was selected to cover all possible variations in relative heading. However, the number of levels was selected somewhat arbitrarily. It was felt that more than three values would be required to adequately cover the range of variation of ϕ , and with five levels, the actual angular values used become intuitively satisfying.

Now, to have obtained a complete replication of the perceived threat factorial, 135 observations of perceived threat would have had to be obtained from each subject (3x3x3x5). However, in the interest of a shorter, more manageable experiment, it was decided to obtain only a fraction of the complete replication. Instead of eliciting five values of perceived threat from each subject at R = 0 for each weapon and exposure time, only one value was obtained. This procedure then permitted an experiment consisting of only 99 observations from each subject [(5 levels of ϕ) x (2 levels of R)x (3 levels of T)x (3 levels of W)plus (1 level of R)x (3 levels of T)x (3 levels of W)]. Thus, an incomplete factorial design was actually employed in the experiment; and, as discussed in the analysis section of this chapter, some problems had to be overcome before satisfactory analyses could be performed upon the data.

The design to obtain zero threat range data was again a simple factorial to be replicated once for each subject. It was anticipated that there would be a subject effect, a weapon effect, an exposure time effect and a relative heading effect. Thus, the design was a (s)x(w)x(t)x(p) factorial with one replication. For simplicity, the levels of the various factors used in the perceived threat experiment were also used in the zero threat range experiment. Hence, the

factorial involved 45 measurements of zero threat range[(5 levels of ϕ)x (3 levels of t)x (3 levels of W)] from each subject.

F(T). To obtain data to estimate F(T), indifference techniques are used as explained in the next section. Essentially, the procedure consists of determining the amount of unexposed travel time T a helicopter pilot would be willing to endure in order to avoid a specified exposed route segment situation. Then, the perceived threat of the exposed route segment situation becomes a value of F(T) for the stated unexposed travel time.

It was suspected beforehand that the range of F(T) would be rather small in comparison to the range of $D_i(R, \phi, T)$. Thus, it would not be that important to determine the shape of F(T) with extreme precision. Therefore, rather arbitrarily, it was decided to determine nine data points from each subject with which to estimate F(T). These nine points came from a 3 x 3 fixed effects factorial involving the factors W and T, with the same levels of these factors being used as were used in the design for $D_i(R, \phi, T)$. That is, W was a qualitative factor at three levels (14.5 mm weapon, 23 mm weapon, and REDEYE weapon) and T was a quantitative factor at three levels (5, 15, and 45 seconds). The factor R was fixed at its second level (40% maximum effective range) and ϕ was fixed at its third level, 90^o.

Additive Disutilities. As the reader may recall, each of the three perception models assumes additive disutilities with respect to exposure to multiple enemy weapons. However, no provision was made in the Phase I

Experiment to test this assumption. While procedures to test the assumption are relatively simple to devise, their inclusion would have involved the addition of another fairly taxing task in an already long and tiring experimental session. Moreover, in an earlier preliminary experiment involving a different subject group,[3] the procedures had been included. While no statistical analyses were performed on the resulting data, it appeared that additive disutilities could indeed be assumed. Thus, in view of the preliminary results and in consideration of the extra effort that would have been involved, procedures to gather data for testing the assumption of additive disutilities were not included.

<u>Method</u>

As stated previously, methods of direct interrogation were used throughout the Phase I Experiment to obtain data from subjects. Again, the only particularly interesting methods were those associated with obtaining data for estimating $D_i(R, \phi, T)$ and $F(T)$. The other data were obtained in a rather straightforward manner.

Methods to be used to measure the 99 values of perceived threat and the 45 values of maximum threatening range had to be relatively simple. Even with only 144 measurements, there was the possibility of subject fatigue. Moreover, the subjects had to be able to understand the meaning of the responses they were being asked to make.

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[3]The preliminary experiment was conducted among personnel of the Ohio Air National Guard. See Appendix G for a brief description of the experiment.

The method used to elicit perceived threat values from a subject for each factor level combination was a direct interrogation method suggested by Dr. James A. Wise of The Ohio State University Department of Psychology. The method had been used successfully by a number of experimental psychologists to obtain numerical data in a variety of subjective evaluation situations. Furthermore, some of these studies had yielded data that could be measured on a ratio scale, while others had employed an interval scale. Notable studies had involved the measurement of subjective probability (Wise, 1970; Mockovak, 1972); however, a wide variety of other types of measurement had also been studied, an outstanding example of which is reported by Peterson and Beach (1967). These investigators found man capable of estimating fairly well all manner of statistical quantities including proportions, means, variances, and correlations, both of samples and of populations.

The problem of determining perceived threat values is very similar to the problems cited above. That is, perceived threat, as defined in this research, is a subjective quantity measurable on an interval scale. This similarity suggests that one may use the direct measurement technique, and this is the approach that was followed. However, no experimental procedure was included to test the psychophysical aspects of the approach. All that can be said is that the results obtained from the experiment appear reasonable.

Now, in the actual experiment subjects were asked to constrain their subjective threat evaluations to the interval (0, 1000). The interval used is really of no importance, but some standard was needed. It was assumed that

subjects would find zero an acceptable value to be associated with no perceived threat. An interval of 1000 was considered adequate to permit a wide range in subject response if the subject so desired. It also contains enough integer values to hopefully prohibit a subject from selecting his favorite number for an answer too often. This last property of the interval is the main reason that more common intervals such as (0, 10) or (0, 100) were not used in the experiment.

Briefly, the direct interrogation method to determine perceived threat consisted of a single session broken into several segments. The segments that were involved may be outlined as follows: (1) a briefing of the subjects to define to them (in terms familiar to military aviators) the concept of perceived threat; (2) a briefing to acquaint the subjects with the enemy weapons to which they would be exposed; (3) a review of the range of variation of all the geometric situation variables to which they would be exposed; (4) a segment in which each subject was asked to determine the situation or situations which he felt to be the most threatening of all situations to be examined; (5) instructions to assign a maximum perceived threat value (1000) to any situation perceived to be equivalent to the most threatening situation determined earlier; (6) instructions to assign zero perceived threat to any situation to which the subject felt no threat; and (7) a segment in which perceived threat values were elicited in response to each of the factor level combinations occurring in the design.

The last segment employed 99 slides, each depicting one threat situation. As the slide was presented, each subject was asked to record his response on a computer data card which was prepunched with the subject number and the slide number. As each card was completed it was placed in a container so that past answers could not be reviewed.

Each slide contained both a visual representation of the situation and written data to define the weapon type, the actual range and the exposure time involved. In addition, as each slide was projected the experimenter read the information aloud.

The sequence of 99 slides was introduced by another sequence of 10 slides of the same type which represented situations appearing at random in the later sequence. The purpose of this introductory sequence was to provide practice in the techniques involved. Thus, the data for these slides have not been included in analysis. The 99 slide sequence was ordered randomly with the following constraint: levels of at least two of the situation factors had to change between one slide and another. This random sequencing was performed by a special computer program designed specifically for the task.

Direct interrogation was also employed to determine from each subject the range at which perceived threat first fell to zero for each combination of weapon, exposure time and relative heading. Upon completion of the 109 slide sequence outlined in previous paragraphs, the subjects were asked to retrieve the handout they had been given earlier which described all threat situations included in the design. This handout had been used to determine the situation

which was considered most threatening. The subjects were instructed to carefully consider the situations and, without regard to perceived threat values they had given earlier, to record on the handout, the range at which they would feel no threat for each combination of weapon, exposure time and relative heading.

Indifference techniques were employed to determine data with which to estimate F(T). However, direct interrogation was still the underlying method of eliciting a response. The method consisted of the presentation of a sequence of 9 slides, each identical in composition to those described earlier. As each slide was presented, each subject was asked to record an unexposed travel time which he would be willing to endure in order to avoid the situation shown on the slide. Again, the subjects were asked to record their responses on prepunched computer data cards and to prepare their answers without regard to other answers given previously. The slides were randomly sequenced by the procedure described earlier.

The sequence was presented after a lengthy introduction was given in which a hypothetical tactical scenario was described in detail. It had been found in preliminary testing with another group of subjects that such an introduction was required before the subjects could offer responses of the type desired. The implications of this finding will be discussed in the analysis section of this chapter.

With data for estimating $D_i(R, \phi, T)$ and F(T), all that remained was to determine: (1) vehicle information; (2) speed information, and; (3) relative overall threat information. Information regarding the maximum effective range

perceived by a subject could be obtained from the data collected to estimate $D_i(R,\phi,T)$.

First, the subjects were asked to specify: (a) the speed they would employ while flying at knap-of-the-earth flight levels, and (b) the speed they would employ were they to conduct an attack with running fire. Previous to this, the subjects were briefed to insure that they understood the mission context in which the speeds would be employed. Moreover, they were asked to assume that they were flying the type of helicopter they felt to be most appropriate to the mission so long as it was one in which they had been checked out. The type of vehicle they assumed for the mission was recorded in addition to the two speeds. Finally, the subjects were asked to comment on the way in which speeds might vary during knap-of-the-earth flight and during a running-fire attack. This information was collected at the beginning of the experimental session.

At the end of the session, the subjects were asked to consider carefully the enemy weapons that had been described to them and to which they had provided perceived threat responses. The subjects were then asked to rank the weapons to indicate in general how they rated the weapons in terms of overall threat. For example, each subject was asked to select the one weapon out of the three he would least like to encounter on the battlefield. This weapon was ranked first. The procedure was repeated for the two remaining weapons.

After the ranking, the subjects were asked to rate the less threatening weapons in relation to the weapon ranked first. A direct measurement was

elicited on the scale (0, 100). These results then provided the relative weapon rating data that were desired for Model Three. No attempt was made to relate these data to the preceived threat data obtained earlier although such an attempt might prove interesting and informative.

Appendix B contains a summary description of all media employed during the Phase I Experiment, including examples of the slides, the computer data cards, representative handout material and a summary text of the important oral presentations made by the experimenter during the session.

The Subject Group

A group of qualified decision-makers was selected from among students in the Aviation Armament Division, Department of Standards and Instructor Training, U. S. Army Aviation School, Fort Rucker, Alabama. These subjects were being trained as helicopter instructors and all had comparable training and experience. In particular, each had served as a gunship pilot in Vietnam, had fired weapons in combat and had been opposed by some form of enemy antiaircraft fire. However, as a group they were poorly trained in the doctrine of helicopter employment in a mid intensity warfare environment.[4]

A summary of the subject group qualifications is presented in Table 1. As may be noted, the group consisted of eight subjects.[5]

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[4] Such doctrine is only now being developed and few Army personnel have even been briefed on the development of this doctrine.

[5] The previous experiment summarized in Appendix G was conducted with a group of five subjects. Thus, the subjects in Phase I were numbered 6 through 13.

Table 1

Subject Group Profile

Subject	Age (years)	Rank	Service Experience (Months)		Flight Experience (Hours)				
						Combat Zone			
			Total	At Present Duty Station	Total	Total	Gun-ship	Troop Carrier	Obser-vation
6	25	Cpt	83	36	1300	900	100	0	800
7	27	Cpt	61	25	1625	750	500	200	50
8	25	Cpt	59	21	1600	800	800	0	0
9	24	Cpt	62	24	1400	860	750	40	70
10	24	Cpt	74	28	1300	850	850	0	0
11	23	Cpt	52	25	2000	1100	1100	100	0
12	34	Cpt	114	16	850	405	300	80	25
13	23	CW-2	42	14	1950	1300	1100	25	75
Average	26	-	68	24	1503	871	675	56	128
Range	23-34	-	42-114	14-36	850-2000	405-1300	100-1100	0-200	0-800
Distribution	-	7 Cpt 1 CW-2	-	-	-	-	-	-	-

Table 1 (Continued)

Subject	Flight Experience (Equipment)*			Weapon Firing Experience			
	Gun-ship	Troop Carrier	Obser-vation	7.62 mm	Rockets	Grenades	Missiles
6	UH-1C	-	OH-6A	√	√	√	
7	AH-1G	UH-1H	OH-6A	√	√	√	
8	AH-1G	-	-	√	√	√	
9	AH-1G	UH-1H	OH-6A	√	√	√	
10	AH-1G UH-1B, C	-	-	√	√	√	√
11	UH-1C	UH-1D, H	-	√	√	√	
12	AH-1G	UH-1D, H	OH-6A	√	√	√	
13	AH-1G	UH-1H	OH-6A	√	√	√	√
Average	-	-	-	-	-	-	-
Range	-	-	-	-	-	-	-
Distribu-tion	UH-1B UH-1C AH-1G	UH-1D UH-1H	OH-6A	8	8	8	2

*The numbers appearing in these columns are official U. S. Army helicopter model designators. The UH-1 series is the familiar "Huey" helicopter that has served in a variety of roles during the Vietnam conflict. The AH-1 series is the newer "Cobra" derived from the "Huey" but designed specifically as a gunship. The OH-6 series is the "LOH" and has served as the standard observation helicopter in Vietnam.

Table 1 (Continued)

Subject	Air Defense Experience (Heaviest Weapon Encountered)					
	.30 cal	.50 cal	37 mm	57 mm	Were you engaged?	Did you engage?
6		√			Yes	Yes
7		√			Yes	Yes
			√		No	No
8		√			Yes	Yes
9			√		Yes	Yes
10		√			Yes	Yes
11	√				Yes	Yes
12			√		No	No
				√	No	No
13		√			Yes	Yes
Distribution	1				Yes	Yes
		5			5 Yes	5 Yes
			3		2 No	2 No
				1	No	No

Subject	Heavy Target Experience			Mid-intensity Warfare Training
	Tanks	Concrete Bunkers	Weapons Used	
6				√
7				√
8				
9	√		Rockets	√
10	√		Grenades	
11		√	Rockets	
12				√
13	√		Every weapon available	
Distribution	3	1	Assorted	4

Conduct of the Experiment

Arrangements for the experiment, including assistance in location of the subject group was provided by Major Gary O. Lozier, Office of Doctrine Development, Literature and Plans, U. S. Army Aviation School, Fort Rucker. His aid was invaluable.

A classroom was reserved with excellent facilities for conducting the experiment. The room was equipped with remote controlled lighting, a screen for viewing slides, a projector, and work tables of sufficient size to permit freedom of movement for the subjects. Adequate room was available between tables to insure independent responses.

As mentioned in Chapter 1 and discussed in the next chapter, the experimental session was to include not only the Phase I Experiment but also a portion of the Phase II Experiment. This Phase II activity involved the selection of routes using map boards and required extensive supervision on the part of the experimenter. For this reason and to prevent undue inconvenience for the subjects, the subject group was divided into two subgroups of four subjects each. The first subgroup commenced the experimental session at 0800 hours on 28 December 1971 while the second subgroup was scheduled to commence at 1000 hours. However, the second subgroup was prevented from starting until 1030 hours by the slowness with which the first session proceeded. The two sessions were identical in all respects.

As each subject entered the room he was randomly assigned a work table. On each table was a numbered supply packet containing the materials described in Appendix B. The number on the packet became the subject number with which he would be identified in all analyses.

The session then proceeded with an introduction in which the overall purpose of the experiment was explained. Following this introduction, the session continued as outlined in the previous section. No problems were encountered as all the experimental procedures had been perfected in the preliminary experiment outlined in Appendix G.

Analysis of Results

Results of the Phase I Experiment are presented in detail in Appendix C. The purpose of this section is to describe the analysis of that data, to present some conclusions that were made regarding the use of the data as input to the route selection model, and to make some preliminary observations on the apparent decision performance of helicopter pilots.

Helicopter Types. Comparison of Table C.1 with Table 1 indicates that with but one exception (subject 6) the type of helicopter selected for the hypothetical mission was the type the subject had flown as a gunship in Vietnam. Thus, it is assumed that the threat perception response data were at least gathered in an environment in which the subjects were associating with a helicopter with which they were thoroughly familiar. By forcing the response the subjects were encouraged to consider the threat situations in this manner.

Speeds. Table C.2 shows that both knap-of-the-earth flight speeds and attack speeds for a particular subject are in general highly variable. This finding is contrary to the assumptions of the route selection model and might indicate an area in which enrichment of the route selection model would be beneficial. Another result apparent in Table C.2 is that there is considerable variation among subjects. Each subject seems to have developed his own personal style through experience. In the absence of a model to accept variable speed inputs, the median value for knap-of-the-earth flight speed was selected as the value to be used during Phase II research. However, because of experimental design requirements of Phase II (discussed in Chapter 4) the attack speed selected for a subject was not necessarily the median value. One speed had to be selected for each subject pair (6, 10), (7, 11), (8, 12) and (9, 13). Thus, it was attempted to select a speed that fell in the range of speeds common to both subjects in a particular pair. The speeds selected for Phase II research are indicated in Table C.2.

Relative Threat Ratings. The data in Table C.3 can be used to compute the relative threat variables (C_i) needed as input for the perceived threat model known as Model Three. A very interesting observation begins to emerge from examination of these data. Even though the subjects had been presented the same information concerning the enemy weapons, the subjects either perceived the information differently or they were operating on a set of preconceived notions developed individually or perhaps in groups. Three of the six possible orderings of the weapons are present, with subjects 6, 7 and 10 giving very

similar results, subjects 8 and 13 giving similar results and subjects 9, 11 and 12 giving similar results. Average results, when normalized, are close to those given by subjects 9, 11 and 12.

As a preliminary observation it appears that the pilot population may indeed by heterogeneous. It was not expected that the pilots would appear so dissimilar with respect to the simple question of an overall rating of enemy weapons. Nearly uniform behavior similar to that exhibited by subjects 6, 7 and 10 or by subjects 9, 11, and 12 had been expected. Thus, this finding served as an initial indication of non-uniform decision behavior among the subjects and led to the belief that further evidence of such behavior would become apparent during analyses of the other data collected.

Maximum Effective Range. The other set of input data required for Model Three, the perceived maximum effective range for each weapon type, can be derived from the maximum threatening range data collected during the second factorial experiment associated with $D_i(R, \phi, T)$. These maximum threatening range data appear in Table C.5. It may be seen that these data vary strongly with exposure time, they are only moderately variable between subjects, and except for the REDEYE weapon, they are almost invariant with changes in relative heading. There is some indication of subject inconsistency when the data are compared with perceived threat data in Tables C.6 through C.8. However, the direct interrogation method used to elicit the data appears to have worked fairly well in that overall trends in the data appear quite reasonable. The differences in data trends for the REDEYE weapon can be traced to the fact that this weapon is much more effective when fired at the rear of the helicopter.

One interesting observation to be made is that for the longer exposure times, subjects tend to consider a weapon threatening at ranges in excess of published estimates of weapon effective range. This trend indicates that the subjects might consider a weapon lethal out to its absolute maximum range capability. Such a trend is indicative of conservative behavior on the part of the pilot population.

Now, the data required for each subject in Model Three is a function of weapon type only. Therefore, an average was taken across exposure time and relative heading to obtain the desired data. Possibly a more representative approach would have been to average the maximum value for the three exposure times across relative heading. Also, Model Three could have been enriched to allow for variation in maximum threatening range as a function of exposure time. However, neither of these alternatives was adopted.

Unexposed Threat Function. The data in Table C.4 represent values of the factor $G(\hat{T})/T$ where $G(\hat{T})$ is the perceived threat value recorded during the experiment to determine data to estimate $D_i(R, \phi, \hat{T})$, $\hat{T}$ is the value of exposure time that was involved and T is the value of unexposed travel time the pilot would be willing to endure to avoid $G(\hat{T})$. This factor can be thought of as the rate of accumulation of threat while unexposed.

First, it appears that the procedure used did not result in a very consistent performance by the subjects. To be specific, no systematic variation can be detected as the factor levels change. Furthermore, it is not apparent that any logical reason should exist to explain why the values vary as they do

as the factor levels of the equivalent exposed situation change. It had been hoped that at least for a given subject, the values for the factor would be almost constant. This would result in a linear form for F(T) and indicate additive disutilities at least between any two unexposed route segments. However, such results were not obtained. Therefore, it is proposed that the variability is strictly an indication of subject inconsistency in the assigned task as it was presented to them. Since the values of $G(\hat{T})/T$ are quite small in relation to the values that exist for $G(\hat{T})$, it is considered to be unimportant that an accurate functional relationship be developed for F(T). Thus, the apparent subject inconsistency is judged to be of little consequence. Hence, F(T) is assumed linear in T for each subject with the average value of $G(\hat{T})/T$ for each subject being used as the constant of proportionality.

Next, the reader will recall that the subject group had to be given a detailed description of the overall tactical scenario before indifference values could be elicited with which to estimate F(T). This finding indicates that the magnitude of the range of F(T) might be a strong function of the overall battlefield situation in which a route is to be planned. Thus, the data collected during Phase I are definitely applicable only to the class of route selection problems studied in this research. However, it is difficult to perceive of militiary route selection problems involving exposure to the enemy in which the magnitude of the range of F(T) would approach in value the magnitude of the range of $D_i(R, \phi, T)$. Thus in future research, it would seem that collection of data to estimate F(T) could be avoided. In fact, it is suggested that the

statement of the Acid Test Model relation be revised as follows:

$$t_s = \begin{cases} \sum_{i=1}^{N} \delta_i \cdot D_i(R, \phi, T) & \text{if a segment is exposed to at least one enemy weapon} \\ K \cdot T & \text{if a segment is unexposed} \end{cases}$$

where K is simply some small fraction (.001) of the magnitude of the range of $D_i(R, \phi, T)$ and all other variables are as defined on page 73 of this chapter.

Perceived Threat. Perceived threat data appear in Tables C.6 through C.8. The associated maximum threatening range data discussed earlier appear in Table C.5. The only observation that may be made about the data in this form is that the direct interrogation method apparently worked fairly well in that overall trends appear quite reasonable. However, some evidence of inconsistent subject performance does exist.

Now, the reader will recall that it is assumed that the jth perceived threat response obtained from a given subject and corresponding to a particular set of values for i, R, ϕ and T can be expressed as

$$O_j = D_i(R, \phi, T) + \epsilon_j$$

where O_j is the response obtained and ϵ_j is a normally and independently distributed random error with zero mean and variance σ^2. With this definition of the underlying phenomenon, the objective of analyses of the perceived threat data was to obtain a statistically accurate and precise estimate of $D_i(R, \phi, T)$.

However, since so little was known about the function, it was decided not to postulate an a priori functional form that might be tested through regression analyses. Instead, it was anticipated that considerable information about the function could first be determined through analysis of variance techniques. Possibly after such an analysis, regression analyses could be more fruitfully applied.

As a start, the most general model possible was assumed. That is, the assumed model included an overall mean, all main effects (subject, weapon, exposure time, range, relative heading), all two-, three- and four-factor interactions and an error term. However, this approach required that the five-factor interaction be assumed zero in order to obtain an estimate of the error term. Had the overall factorial been replicated, such an assumption would not have been required.

Now, as mentioned in a previous section, the design used to obtain the data presents some problems if one wishes to perform exact statistical analyses of the data. The design was inherently unbalanced since no variation in relative heading was considered for the first level of separation range ($R = 0$). That is, only one replication at $R = 0$ was performed when in fact, five replications should have been performed.

One approach to solving the problem would be to analyze only the two intermediate levels of R (40% and 80% maximum effective range). However, this approach presents a dilemma since only a linear effect in range could be determined; and as stated earlier, it was desired to obtain estimates of at

least a quadratic effect for all factors. Furthermore, an appreciable amount of the information available would not be used. Therefore, for the sake of simplicity and in view of the desire to obtain statistical insight with regard to the overall shape of the response surface, the analysis performed was approximate. First, the available data set was modified so that the one value of perceived threat that existed at R = 0 for each subject, exposure time and weapon type was repeated four times. In other words, the data were analyzed as though a complete factorial experiment had been conducted in which the five replications required at R = 0 had been obtained. Unfortunately, this step results in errored estimates of all quantities in the model, but the error is hopefully small. For example, Table 2 shows the contribution of possibly erroneous readings in the computation of marginal means for each main effect, expressed as the absolute number of possibly erroneous readings and as a percentage of the readings comprising each mean. It is seen that for most effects, observations that are possibly erroneous account for 20% of the marginal mean observations. However, the marginal means for relative heading and separation range consist on the average of 27% errored observations. Moreover, 80% of the observations comprising the marginal mean associated with the first level of range are possibly in error. Unfortunately, no data were gathered to indicate how much intrapersonal variation might exist since no replication was performed. If intrapersonal variation is small, then the analysis is relatively free of error.

Table 2

Contribution of Possibly Erroneous Observations

Marginal Mean	Number of Errored Observations	Total Number of Observations	%
Subject	36	135	20
Weapon	96	360	20
Exposure Time	96	360	20
Separation Range			
Level 1	288	360	80
Level 2, 3	0	360	0
Average	96	360	27
Relative Heading Average	57.6	216	27

A saving factor does exist, however. The errors of which we are concerned affect only the determination of which factors and interactions are statistically significant. If certain factors and interactions appear overwhelmingly significant in an analysis of variance it might be assumed that observations without error would not affect conclusions to be drawn. Plots of the marginal means would still indicate data trends giving rise to the variation.

With all the cited approximations in mind we present at Figure 7 an analysis of variance table for the perceived threat experiment. It is readily apparent from this type of analysis that: (1) with the exception of the weapon

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Separation Range	2	917,618	458,809	$\sigma_e^2 + 360\sigma_1^2 + 45\sigma_{13}^2$	
2-Weapon Type	2	848,813	424,066	$\sigma_e^2 + 360\sigma_2^2 + 45\sigma_{23}^2$	
3-Subject	7	7,573,518	1,081,931	$\sigma_e^2 + 135\sigma_3^2$	***
4-Exposure Time	2	108,724,506	54,362,240	$\sigma_e^2 + 360\sigma_4^2 + 45\sigma_{34}^2$	***
5-Relative Heading	4	1,497,850	374,463	$\sigma_e^2 + 216\sigma_5^2 + 27\sigma_{35}^2$	***
12	4	1,611,115	402,779	$\sigma_e^2 + 120\sigma_{12}^2 + 15\sigma_{123}^2$	***
13	14	3,757,640	268,403	$\sigma_e^2 + 45\sigma_{13}^2$	***
14	4	1,597,581	399,395	$\sigma_e^2 + 120\sigma_{14}^2 + 15\sigma_{134}^2$	*
15	8	817,075	102,134	$\sigma_e^2 + 72\sigma_{15}^2 + 9\sigma_{135}^2$	***
23	14	6,022,768	430,198	$\sigma_e^2 + 45\sigma_{23}^2$	***
24	4	655,243	163,811	$\sigma_e^2 + 120\sigma_{24}^2 + 15\sigma_{234}^2$	
25	8	2,884,528	360,566	$\sigma_e^2 + 72\sigma_{25}^2 + 9\sigma_{235}^2$	***
34	14	5,221,514	372,965	$\sigma_e^2 + 45\sigma_{34}^2$	***
35	28	2,050,061	73,216	$\sigma_e^2 + 27\sigma_{35}^2$	***
45	8	841,078	105,135	$\sigma_e^2 + 72\sigma_{45}^2 + 9\sigma_{345}^2$	***
123	28	1,042,468	37,230	$\sigma_e^2 + 15\sigma_{123}^2$	***
124	8	1,489,732	186,216	$\sigma_e^2 + 40\sigma_{124}^2 + 5\sigma_{1234}^2$	***
125	16	1,750,701	109,419	$\sigma_e^2 + 24\sigma_{125}^2 + 3\sigma_{1235}^2$	***

Figure 7. --Analysis of Variance for the Perceived Threat Experiment

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
134	28	4,299,961	153,570	$\sigma_e^2 + 15\sigma_{134}^2$	***
135	56	1,559,694	27,852	$\sigma_e^2 + 9\sigma_{135}^2$	***
145	16	661,969	41,373	$\sigma_e^2 + 24\sigma_{145}^2 + 3\sigma_{1345}^2$	***
234	28	4,636,343	165,584	$\sigma_e^2 + 15\sigma_{234}^2$	***
235	56	1,620,486	28,937	$\sigma_e^2 + 9\sigma_{235}^2$	***
245	16	654,190	40,887	$\sigma_e^2 + 24\sigma_{345}^2 + 3\sigma_{2345}^2$	***
345	56	1,156,340	20,649	$\sigma_e^2 + 9\sigma_{345}^2$	**
1234	56	2,392,846	42,729	$\sigma_e^2 + 5\sigma_{1234}^2$	***
1235	112	2,152,489	19,219	$\sigma_e^2 + 3\sigma_{1235}^2$	**
1245	32	950,913	29,716	$\sigma_e^2 + 8\sigma_{1245}^2$	***
1345	112	1,691,697	15,104	$\sigma_e^2 + 3\sigma_{1345}^2$	*
2345	112	1,947,036	17,384	$\sigma_e^2 + 3\sigma_{2345}^2$	*
Residual	224	3,064,944	13,683	σ_e^2	
Total	1079	176,091,808			

Figure 7.--Analysis of Variance for the Perceived Threat Experiment (continued)

Note: * Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

and separation range factors, every other factor considered in the experiment was indeed important; and (2) a very complicated set of interactions exists among all factors studied.

At first glance, the lack of a weapon effect is very surprising since it had been expected that the type of weapon being considered would strongly influence the pilots' perception of threat. The negative result can be explained, however. It was noted earlier in the discussion of the overall enemy weapon rating data obtained for Model Three that the pilots differ widely in their relative rankings of the weapons. This phenomenon is further illustrated in Figure 7 where it may be noted that there is a very strong interaction between the subject factor and the weapon factor. Thus, it is possible that an analysis of variance performed for each individual pilot might reveal that a weapon effect does exist for at least some of the pilots. In fact, such an analysis was actually performed and it was found that all eight subjects did register a weapon effect.

The lack of a separation range effect is also explainable. The reader will recall that the maximum separation range considered in the experiment was only 80% of the published maximum effective range of the three types of enemy weapons. It is entirely possible that the pilots consider the weapons to be almost uniformly threatening out to a range in excess of this 80% value. Indeed, as was discussed previously, an analysis of maximum threatening range data (Table C.5) indicates that under certain conditions the subjects consider the weapons threatening to ranges in excess of the maximum effective range itself.

Table 3 shows the relationships that exist between the maximum ranges used in the experiment and the marginal means computed from the maximum threatening range data.

The reader should note that the lack of a separation range effect lends at least partial support to Model Three as a perceived threat model. In this model, an enemy weapon is considered threatening if it is within the maximum effective range assigned to it by the decision maker .

Table 3

Maximum Threatening Range Relationships

	Weapon Type		
	14.5 mm	23 mm	REDEYE
Maximum Range Used	1200	2400	2800
Marginal Mean for T = 5 seconds	432	918	1277
Marginal Mean for T = 15 seconds	1264	2812	2829
Marginal Mean for T = 45 seconds	1570	3018	3249

Examination of the sums of squares column in Figure 7 reveals that exposure time is by far the most important factor as had been anticipated. In fact, over 60% of the total variability can be attributed to this factor. However, the fact that approximately 40% of the total variability remains unaccounted for indicates that the Acid Test model should still consider factors other than T alone.

Another interesting observation is that almost all of the exposure time variability can be attributed to a linear effect. Specifically, by the use of orthogonal polynomials, it was determined that 98% of the variation is explainable as a linear effect. This finding lends support to the assumption of a linear relationship between exposure time and perceived threat in the Acid Test Model. Moreover, the linear relationship assumed in Model One and Model Three are apparently quite reasonable.

The fact that there is a relatively strong subject effect lends more credence to the proposition that a considerable overall difference exists between pilots, at least with respect to their perception of threat. However, a more important result is that some evidence exists to suggest that the pilots apparently differ even with respect to the way in which they view the dependence of perceived threat on the situation variables. For example, approximately 10% of the total variability can be attributed to two factor interactions involving the subject factor. In comparison, the set of weapon two-factor interactions contributes only 6%, of which the subject-weapon interaction is over half. The other sets of two-factor interactions contribute less than 5% each, with the subject-factor interaction contributing about 50% to each set on the average.

Examination of the residual indicates that less than 2% of the total variability is unaccounted for by the effects and interactions considered. This result indicates that the model is very good at representing the response surface. However, examination of the list of significant factors and interactions indicates that the response surface is an extremely complex function of the independent variables. Thus, it would be very difficult to propose a functional form for

$D_i(R, \phi, T)$ to be studied with regression analyses. Hence, the decision was made that the data for each subject would be used in raw form as input to the route selection model in order to permit studies involving the Acid Test threat perception model. A procedure would be incorporated into the route selection model to linearly interpolate between data points in order to define the perceived threat (DIJMN) for any route segment. Considering this result, all the attention paid previously to the approximations involved in analysis of the threat perception data was certainly important for understanding but of little consequence in the final analysis.

Additive Disutilities. One result of the findings in the previous paragraphs is that if a decision maker did in fact perceive threat as predicted by the Acid Test Model, then the additivity assumption of Chapter 2 would be violated. Not only do complex interactions exist among the effects of the geometric variables, but the effects of the individual factors themselves exclude the possibility of additive segment disutilities to compute route disutility. For example, there is a fairly strong dependence upon the variable ϕ as indicated by its significance. Moreover, by the use of orthogonal polynomials, it has been determined that 94% of the variability can be attributed to a linear effect. Now, as indicated previously there is also a strong linear effect in T but no R effect. Even if there were no interactions among these effects, additive disutilities could not exist.

As an illustration of this observation, suppose the relation for perceived threat were simply

$$D = a\phi + bT$$

where a and b are constants that might be determined through regression analyses. Now suppose, as in Figure 8, a helicopter flying at a speed of 80 knots were approaching a route segment, the execution of which would result in a total exposure time of 45 seconds. As illustrated, the midpoint of the segment is 600 meters from a 14.5 mm weapon located directly abeam of the segment. Direct evaluation of perceived threat for this situation yeilds the result

$$D = \pi/2\ a + 45\ b\ .$$

Now, instead of direct evaluation, suppose that the segment were divided into three subsegments with each subsegment representing 15 seconds exposure as illustrated. If valuewise independence exists then the segmented evaluation should yield the same results as the direct evaluation scheme. However, such is not the case. The result is approximately

$$D = 3\pi/2\ a + 45\ b\ .$$

As can been seen the only way in which additive disutilities could exist would be for the constant a to be zero, a result contrary to the findings of the analysis of variance.

As an additional check on the above result, an analysis of the type outlined was performed using actual perceived threat data from Tables C.6 through C.8. The direct evaluation scheme employed 45 second exposure time data

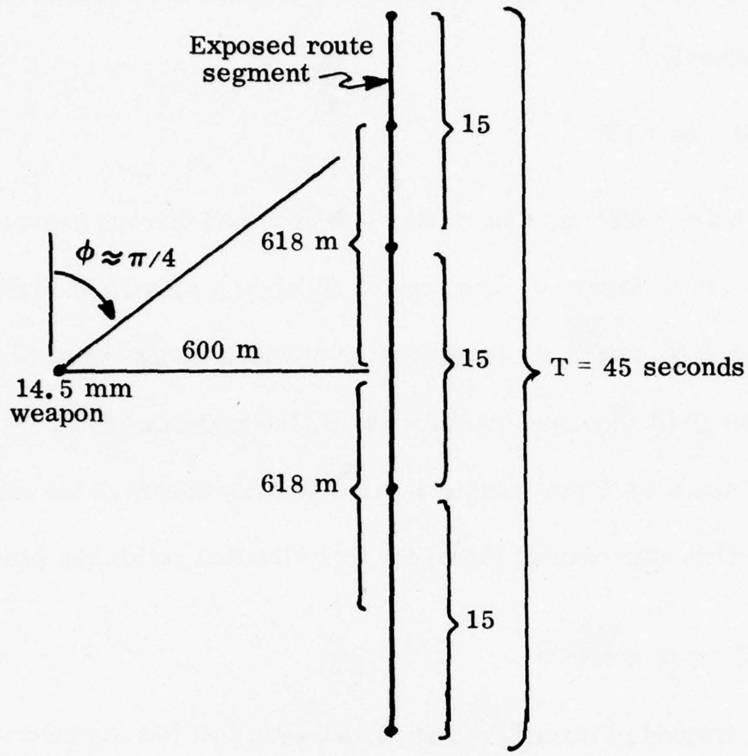

Figure 8.--Schematic of Threat Evaluation Alternatives

Table 4

Comparison of Threat Evaluation Results

Subject	Direct Evaluation	Segmented Evaluation	Percent Difference
6	900	1917	113
7	500	1384	177
8	800	1313	65
9	985	2233	127
10	1000	2133	113
11	900	1251	39
12	900	1609	79
13	975	1706	75
Average	870	1693	95

directly from the tables, and the results appear in the column labeled "direct evaluation" in Table 4. Data for 15 second exposure time were interpolated from the tables with the final results appearing in the column of Table 4 labeled "segmented evaluation." As can be seen the two sets of results are quite different, with differences of more than 100% very common. Such results are in agreement with those of the simple analysis cited earlier.

The implications of these findings are discussed in more detail in Chapters 4 and 6. However, the principal implication is that the route selection model can only approximately select routes for decision-makers who do indeed perceive threat as described by the Acid Test Model. To select routes exactly would require that the additivity assumption be dropped. This would involve a modification of the route selection model that is beyond the scope of the present research.

CHAPTER 4

PHASE II EXPERIMENTATION

by Don C. Hutcherson

Introduction

In this chapter a comprehensive description of the Phase II Experiment is presented. The reader will recall that the overall purpose of this experiment was to test the predictive qualities of the route planning model derived in Chapter 2. More precisely, the experiment was intended to determine how well a route predicted by the model might fare in comparison with a route that might actually be planned by a decision maker, given a particular tactical situation. In addition, the experiment was intended to determine which of the three threat perception models proposed in Chapter 3 is most appropriate for use in the route planning model. Finally, it was desired that the Phase II Experiment should yield more information about the decision processes employed by a pilot in the route planning task and about differences that might exist among pilots in this decision task.

One of the first and most critical research tasks associated with Phase II was development of methods to be used in measuring the "goodness" of routes predicted by the route planning model. Without such methods it would be difficult to determine how well such routes fare in comparison to routes actually selected by decision makers. Moreover, it would be difficult to determine which of the three threat perception models should be used in the route selection model.

The second major task associated with Phase II was development of an experimental design to be used in gathering data. The design had to yield the required information efficiently and could not be too extensive since human subjects were being used.

The final Phase II research task was associated with analysis of data gathered during the experiment. During this task, conclusions were formulated with respect to the performance of the route selection model in general and the three threat perception models in particular. In addition, further conclusions about pilot decision making behavior in the route planning task were reached.

All the topics discussed above are described at length in the remaining sections of this chapter. First, the method selected to measure the "goodness" of a route predicted by the planning model will be discussed along with the techniques employed to obtain such measures. Then, the experimental design developed to gather the required data is discussed. Finally, conduct of the experiment and analyses of the results are presented as separate topics.

Validation Measure

As stated previously, development of methods to be used in validating the predictive qualities of the route selection model was one of the most crucial activities performed during the Phase II portion of the research program. Since the route selection model had been constructed in response to a hueristic theory whose individual elements had not been tested as part of the research program, it was critically important that a good method be developed to determine how the model performed as a whole.

From the very beginning it was clear that the predictive qualities of the model could not be evaluated objectively. Given that the model was intended to predict the routes that individual pilots would select when faced with specific tactical situations, it was obvious that the performance of the model could be judged only by those for whom the predictions were intended. Moreover, it was anticipated that there would be no objective basis from which these judgments could be rendered. For example, it is highly unlikely the prediction model would duplicate exactly the route chosen by an individual pilot. Because of the limitations imposed by the method used to construct route alternatives in the model, a subject might choose a route which is not part of the hypothesized set of alternatives but which is close to several members of this set. Thus, the predicted route would almost always differ in some respect from the route the subject had chosen. A diverse set of objective similarity measures could be developed to describe these differences, but the relative importance of each measure would remain a matter of judgment.

It was decided then, that the experimental subjects would be asked to develop a route plan for each of several tactical situations. Following this they would be asked to make direct comparisons between the routes they chose and the corresponding predicted routes developed by the route selection model. The direct interrogation method had been used successfully during Phase I and was felt to be at least as applicable to the Phase II Experiment. In fact, the Phase II task was almost identical to some of the tasks performed by subjects in experiments conducted by Lawrence (1968). In his studies, alternative methods of preparing armored combat battle plans were subjectively ranked and rated by the subjects, and the procedure proved to be quite successful.

One approach that was tried in the preliminary experiment (Appendix G) was to have each subject rank a set of routes that included the route he had chosen and several alternative routes developed by the route selection model. The route considered to be the most preferred for the specified situation was ranked first by each subject. Then each subject compared the remaining routes and ranked the best one remaining second. The process continued until all route alternatives had been ranked. As the routes were ranked, they were also rated on a scale of zero to one hundred to indicate the subjective worth of the alternative routes relative to the route ranked first. The route ranked first was given a rating of one hundred.

While the above procedure produced reasonable results and was easily executed by the subjects, it was felt that the procedure would not be acceptable for application during the Phase II Experiment. The experimental design employed (to be discussed) resulted in a very large number of alternatives for each route selection situation. It was feared that the subjects would find it difficult to examine such a large set of alternatives simultaneously and render meaningful judgments. Therefore, the following procedure was used. Each subject was asked to perform a series of comparisons between only two alternatives. In each case, one alternative was the route he had planned himself and the other alternative was one of the routes predicted by the route selection model. The subject indicated which route he preferred and the rating that the "non-preferred" route would receive on a scale of zero to one hundred. Moreover, the regions of the rating scale were given definite qualitative meanings to permit the subjects to associate a rating with their feelings about a pair of route alternatives.

The association was as follows:

100: the two routes are equally preferable,

95-99: the two routes are judged to be almost identical,

70-94: one route is mildly preferred to the other, and

0-69: one route is strongly perferred to the other.

The subjects were told that should they judge a pair of routes to be in the first category above, that they should have to flip a coin to determine which route would be followed. If a pair of routes were judged to be in the second category then they should be so close to one another in preference that no specific reason for selecting one route over the other could be cited, although a preference would exist. Finally, the subjects were told that the last two categories should contain routes for which specific reasons for preference could be cited. Whether mild preference or strong perference exists would be merely a matter of degree. If a major criterion used by a subject for route selection were flagrantly violated by a particular alternative, strong preference should exist for the other alternative.

The method outlined above has one advantage in that it results in fairly easy tasks for a subject to perform. The concepts involved are also simple enough to permit quick understanding by the subjects. Finally, the rating given to a particular route alternative takes on a definite qualitative meaning so that the relative "goodness" of a route may be inferred from its rating. There are definite disadvantages to the method, however. First, the procedure is not sufficient to construct a complete ordinal scale. Next, a test for intransitivity as

exhibited by the presence of circular triads for example, is not available. Finally, there is the possibility of bias in favor of (or against) the route the decision-maker planned himself since he always rates route alternatives against the route he knows he selected. The first two of these deficiencies would have required a tremendous amount of labor on the part of the subjects and the experimenter to correct. Unfortunately, the time available for contact with the subjects was insufficient for a complete ordinal scaling. The last deficiency could be avoided only if some method were available to conceal the identity of a subject's personal plan. Such methods were not incorporated in the Phase II experimental plan.

Experimental Design

Characteristics of the design developed for the Phase II Experiment can best be understood by an analysis of the types of information that were desired as output. First, of course, was the desire to determine which model (or models) of perceived threat was the best to be used in the route selection model. This suggested that the qualitative factor M should be included in the design, where M stands for type of perceived threat model. The effect of this factor would be fixed, and the number of levels m would be three.

Second, there was the desire to determine how the model performed in a variety of tactical situations. Coupled with this, there was a desire to determine how the model fared as a function of the decision-maker doing the evaluation of its results. To obtain a true subject effect it was obvious that at least two subjects would have to be presented with the same tactical situations. In

order to study as many tactical situations as possible with a fairly simple design and still measure a true subject effect, it was decided to form subject pairs who would be presented the same set of tactical situations. This decision worked out well since the subject group available for evaluating the route selection model results was constrained to be the group from which input data had been collected during Phase I. Of course this meant that eight subjects were available. Thus, the qualitative subject factor S was measured at $s = 2$ levels. Also, since the subjects had been selected at random, the subject effect was considered random. The subject pairs were (6, 10), (7, 11), (8, 12), and (9, 13).

Now, each subject pair was presented with a basically different tactical situation in which routes were to be planned. Each situation was the same in that the battlefield over which routes were desired was the same, and two enemy weapons were present in each case. However, the situations were different in that the position and type of each enemy weapon changed, but in all cases the types of weapons used were constrained to be those that had been analyzed during the Phase I Experiment. A summary of the tactical situation layouts appears in Appendixes A and D.

Four different route plans were prepared by each subject in a subject pair. Thus, the qualitative route (or situation) factor R was measured at $r = 4$ levels. Moreover, because of the way the levels were selected, R was considered to produce a fixed effect. In general, the four routes differed only with respect to the starting points specified and the targets to be attacked. Routes 1 and 3 started from the left (or west) side of the battlefield while routes 2 and 4 started from the

top (or north) side of the battlefield. The starting positions for routes 1 and 3 were not intervisible with either of the enemy weapons while routes 2 and 4 started from positions that were intervisible with at least one of the weapons. In general routes 1 and 2 were to be prepared in such a way as to permit an attack upon one of the enemy weapons while routes 3 and 4 were directed at the other weapon. Detailed information concerning the four routes for each tactical situation is contained in Appendix A and Appendix D.

Next, there was a desire to gather information about the decision process by which a pilot selects running fire as opposed to hover fire. From Chapter 2 the reader will recall that these two attack modes differ in that running fire employs a forward speed during the entire attack while hover fire employs a "pop up" to a firing position. Even though a subject was allowed to select either type of fire as part of his route plan, the route selection model was exercised to determine the best route plan for both attack modes. Thus, the qualitative attack mode factor A was measured at $a = 2$ levels and was considered to produce a fixed effect.

Finally, a block effect was introduced as follows. It was desired to determine whether the route selection model would be evaluated more favorably by a decision maker if threat perception data used in the route selection model were in fact the data provided by him during Phase I. Thus, one set of route alternatives were prepared in which the input data used were those collected during Phase I. Another set of alternatives was produced in which the input data used were those obtained by averaging the data collected from all subjects during Phase I. If no data set block effect were found to exist and if the block effect did not interact

with the subject effect then it could be assumed that the subjects came from a homogeneous population of pilots. Moreover, it could be assumed that the route selection model could operate on population average data as opposed to data from individuals. Thus, the data set block factor D was measured at d = 2 levels and was considered to produce a fixed effect. For purposes of identification the alternatives produced by the average input data were called the "super subject" alternatives. The super subject was essentially a ninth subject in the experiment.

From all previous discussion in this section, it can be seen that the overall Phase II experimental design consisted of four independent five-factor complete factorial experiments. That is, the design consisted of four (s)x(r)x(m)x(a)x(d) complete factorials where the symbols are as defined in previous paragraphs. Thus, a total of 96 observations were collected in each factorial for a grand total of 384 observations.

The model assumed for analysis purposes included all main effects and all two-factor interactions, with all three factor and higher order interactions assumed to be zero. This model applied to each of the four factorial experiments. Finally, all five factors were qualitative, and four out of the five were considered to produce fixed effects.

Conduct of the Experiment

As mentioned in Chapter 1, the first step of the Phase II Experiment was actually conducted during the experimental session devoted primarily to the Phase I Experiment. During this step each subject was asked to plan the four routes discussed in the previous section. As a second step in the Phase II

Experiment, data collected during Phase I were prepared as input data for the route alternatives specified by the experimental design. The final step consisted of an experimental session in which the subjects were confronted with the route alternatives and asked to rank and rate the alternatives in the manner described earlier.

Now, because some reaction time was necessary between the Phase I experimental session and the final Phase II session in order to permit execution of the experimental design with the route selection model, the possibility of an unwanted block effect arose. However, it was impossible to eliminate the possibility. It was desired that the subjects prepare their route plans while the concepts discussed during Phase I were still fresh in their minds and while an intimate knowledge of the enemy weapons characteristics still existed. If the route planning exercise had been postponed until the route alternatives were available these benefits would have been lost.

Step 1. The first step of Phase II was accomplished at Fort Rucker, Alabama on December 28, 1971. After completion of the Phase I experimental session, a brief discussion of the route planning task was presented. The subjects were asked to recall the tactical scenario that was described as an introduction to the unexposed threat exercise of Phase I (see Appendix B). Moreover, they were asked to plan their routes as if this scenario applied in each of the tactical situations for which routes were desired.

Next, the subjects were distributed a brochure describing the characteristics of the TOW missile system. They were told to study the document carefully

as this would be the weapon they would employ during execution of each route. Furthermore, they were told that the planned routes could utilize either running fire or hover fire, should include just one attack upon a target, and the attack should conform to the capabilities of the TOW weapon system.

Next, a composite map board was distributed to each subject showing the boundaries of the battlefield, elevation contour lines, boundaries of forested areas, locations of the two enemy weapons and regions in which intervisibility existed with each of the weapons from a knap-of-the-earth flight altitude. This last feature of the map board represented a departure from reality in that it made more information available to the subject than he normally has in combat. However, the LOS[1] maps were included to make up for two factors. First, the type of contour map used was prepared by computer and was a departure from the type of map normally used by a military pilot. Second, the pilot would normally have some familiarity with terrain over which his mission is to be conducted. In fact, a pilot can frequently see the terrain over which a route is to be flown at the time he plans his route.

Next, each subject was distributed a variety of materials to be used in drawing routes. These included grease pencils and clear acetate overlays for recording routes and several scales to be used in measuring time and distance.

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[1] Line of sight (see Chapter 2 and Appendix A).

Finally, the subjects were given a set of preprinted forms describing the details of each route to be planned and providing answer spaces for recording various characteristics of the routes selected. The subjects then recorded their routes as directed. A representative sample of the materials provided each subject is presented and described in Appendix D.

Step 2. The second step of Phase II consisted of preparing data collected during Phase I as input to the route selection model and then exercising the model as prescribed by the experimental design. This task required approximately four weeks to complete, with another two weeks required to prepare the results in such a way that they could be presented to the subjects for evaluation.

Each time the route selection model was exercised at a given combination of factor levels, a deck of cards was produced which gave the coordinates of the end points of each segment in the resultant route. These decks were collected, collated and used as input to another computer program that generated instructions to a two-dimensional plotter. In turn, the plotter produced a translucent overlay depicting the route.

Now, the route description decks were collated in such a way that a given overlay would depict as many as three distinct alternatives for a given route selection situation. The factors S (subject), A (attack mode), R (route/situation) and D (data set) were held constant for each overlay with the only variable being M (perception model). The resultant alternatives on each overlay were annotated

to identify: 1) the direction of motion, 2) the point at which the missile was launched, and 3) the number of the alternative. In no way could a subject identify the perception model being used to select a given alternative.

In the course of preparing the alternative overlays it was discovered that in many instances two different combinations of factor levels would produce the same route alternative for a given situation. Thus, instead of producing a complete factorial layout a design in which certain observations were missing was being produced. That is, instead of a subject being presented with 12 route alternatives for each route he had selected, a fewer number of distinct alternatives was being produced. The ramifications of this development are discussed in the analysis section to follow.

Step 3. The final step of the Phase II experimentation plan was conducted at Fort Rucker on February 15, 1972. The subjects were divided into two groups of four subjects each as had been done during Phase I experimentation, with the first group commencing its session at 0800 hours. The second group was scheduled to start at 1000.

Two groups were desirable to permit closer supervision of the subject activities. Furthermore, facilities available for the session were marginal with room barely available for four subjects. Finally, only one set of super subject route alternatives had been prepared. The two sessions were identical in content.

After preliminary instructions, the subjects were handed the packets of materials described in detail in Appendix D. First, the subjects transferred the routes they had prepared during Phase I from the clear acetate they had used

earlier to the opaque situation maps contained in their supply packet. This activity had two purposes. First, it served to refamiliarize them with the situations they had faced during Phase I and the routes they had planned as a response. It also served to produce a more suitable experimental medium to be used with the translucent route alternative overlays to be used later.

Next, the subjects were given ranking and rating instructions corresponding to those described in an earlier section of this chapter. The subjects then began the ranking and rating exercise, and they all appeared to be enthusiastic in their efforts. For the most part they were amazed that a computer could be made to perform a decision function in which the results were so visible and so dynamic. Some subjects were very conscientious in the task and added copious remarks to their evaluation forms to indicate their reasons for particular rankings.

During the two sessions it was discovered that two of the subjects had misinterpreted instructions during Phase I and had prepared their route plans erroneously.[2] The subjects were asked to make a note of their misinterpretation on their answer sheets and to continue by using their erroneous routes in an unaltered form. Examination of their response data later led to the conclusion that their data were biased in favor of the route selection model alternatives. Consequently, their data were dropped from consideration in all later analyses. The ramifications of this decision are discussed in the analysis section to follow.

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[2] The subjects had erroneously assumed that a firing position could not be selected over terrain that was indicated to provide protected routes for helicopters flying a knap-of-the-earth flight profile. They failed to realize that one could climb to a firing position from anywhere within the range of the TOW weapon system.

Analysis of Results

An obvious first step in the analysis of results was to perform an analysis of variance upon the data obtained from the Phase II Experiment. However, because of developments alluded to in the preceding section the analysis was not as straightforward as had been intended. First, because data for subjects 9 and 10 had been dropped, there were only two of the five-factor factorials instead of the four anticipated. The other two factorials degenerated into four-factor factorials with no subject factor. Second, because different factor level combinations did not always produce unique alternatives, the originally intended complete factorials degenerated into incomplete factorials. As an example of an extreme case, subject 6 was presented only five alternatives for route 1 instead of a possible twelve alternatives.

Table E. 1 shows the numbering scheme for alternatives as presented to the subjects during Phase II. From this table one may partially infer the amount of overall degeneration that actually occurred. However, degeneration also occurred between subjects, but this fact is not revealed in Table E. 1 because of the numbering scheme presented.

Therefore, an interesting problem occurred before the analysis of variance could even be attempted. Some method had to be developed to account for the missing data. Also, it was found through further analyses of the problem that some interesting observations could be made concerning the performance of the model without even examining the data collected during Phase II.

Analysis of Missing Data Phenomenon. The factors that can produce missing data are limited to the subject factor S (between 7 and 11 and between 8 and 12), the perception model factor M (1-Model One, 3-Model Three, AT-Acid Test Model), and the data set factor D (1-personal data set, 2-super subject data set). The attack mode factor A (RF-running fire, HF-hover fire) and the route factor R (1,2,3,4) cannot result in missing data. Table E.2 shows the degree to which missing data occurs as a function of the levels of D; Table E.3 gives comparable results for M and Table E.4 shows the effect of S.

Now, analysis of Table E. 2 shows that if one were to combine all subjects, a study of the block effect D would be based upon data of which only 55% of the observations reveal a true block effect. This fact indicates that for the overall variations that existed between subjects during Phase I, the route selection model is, to a degree, insensitive. However, further analysis reveals that Model One is the chief culprit. If one were to drop Model One from the analysis, then only 16% of the observations would be missing. Thus, without Model One, the route selection model can be considered to be very sensitive.

Of course, there is a logical explanation for this finding. Model One is almost totally insensitive to personalistic data as discussed in Chapter 3 and this fact shows up in the performance of the route selection model. Thus, whether one were studying route selection with personal data or population estimates should make little difference. One might note also that on the average, the route selection model using the Acid Test Model appears to be more sensitive to population variance than it does with Model Three. This tendency was also anticipated in Chapter 3.

Another interesting observation from Table E.2 is that for almost every subject, route 1 alternatives appear to duplicate themselves most often. The most reasonable explanation is that route 1 started from the left side of the battlefield and included an attack upon the closest target. Thus, there might have existed fewer reasonable alternatives for route 1 than for the other routes. This is especially true for subject 6 and for subjects 8 and 12 (see the tactical situation layouts in Appendix A).

Analysis of Table E.3 shows that the degree of duplication as a function of the perception model used is much less pronounced, although some duplication still exists. First, Model One produced results that were unique in comparison to either of the other two models. Thus, Table E.3 shows only the duplication produced by Model Three and the Acid Test Model. One observation to be made from this finding is that there is some indication that the route selection model operates with Model One in a fashion that is distinct from its operation with either of the other two models. Such a conclusion would not be too surprising considering the definitions of the models in Chapter 3.

Also from Table E.3, there is some indication that differences between the tactical situations for which the route selection model determines routes can influence the degree of similarity in results produced by the Acid Test Model and Model Three. For example, in the results produced by the super subject data set, there is no variability attributable to differences in subjects. Therefore, a pure situation effect can be determined. We note then that the subject pair (7, 11) produces the same similarity results, the subject pair (8, 12) produces the same

similarity results, and had data for subjects 9 and 10 been included, similar findings would have applied to the pairs (6, 10) and (9, 13). Given this background, it would appear that the Acid Test Model produces results that differ more often from those produced by Model Three in the situations faced by subject pair (7, 11) and by subject pair (9, 13). Introducing subject variation does not change this observation. In fact, with subject variation the amount of duplication increases generally, with the most severe increase appearing in the situation faced by subject pair (8, 12). No adequate explanation can be offered for the above observations other than the situations faced by subject pairs (7, 11) and (9, 13) may be more complex and hence offer a larger number of reasonable route alternatives. However, the most important conclusion to be drawn is that the situation for which a route is selected may influence the performance of the model. However, the effect may not be as great as that produced by varying the input data set.

Table E.4 presents a summary of similarity generated by comparing alternatives presented to each subject in a subject pair. Of course, the analysis applies only to data set 1 (personal data set) since data set 2 (super subject data set) produces 100% similarity in all cases. Table E.4 was prepared assuming that for each subject-route combination, six alternatives were actually presented based on the combinations of factor levels that were being represented (3 levels of M and 2 levels of A). If in fact an alternative turned out to be missing because the factor level combination did not produce a unique alternative, then the alternative that was missing was of course treated as being identical to the one that was actually presented.

Overall, it can be seen that a large amount of duplication exists, with over half of the observations being duplicated. Moreover the subject pair (7, 11) experienced less duplication than the subject pair (8, 12); and route 1 produced more duplication than the other routes, with route 2 a close second. These last two findings are in agreement with those reported earlier.

Now, a large amount of duplication would be desired if one were wanting to measure a true subject effect as far as evaluation of the route selection model is concerned. Since almost half of the observations are not duplicates, analyses conducted to determine the effects of subject to subject variation would be largely in error if the analyses were based upon results obtained by using data set 1. The more logical choice would be the set of results obtained from data set 2 because 100% duplication occurs.

The overall observation to be made is that the intrapersonal variation measured in Phase I does not appear to produce extremely large variations in the performance of the route selection model. Thus, this observation is in agreement with that reported earlier. Moreover, if the effects of Model One were separated from the effects of the other two models as was done earlier it is felt that most of the similarity could be attributed to Model One.

<u>Analyses of Variance.</u> To solve the problem of missing data so that analyses of variance could be conducted, an approach similar to that followed during the analysis of Phase I data was taken. That is, for each data cell in which an observation was missing, we took as an estimate of the observation the value that was actually realized during Phase II. For example, subject 6 was presented

only five alternatives for route 1. The data which were realized during Phase II were as follows:

Personal Data						Super Subject Data					
AT		1		3		AT		1		3	
RF	HF	RF	HF	RF	HF	RF	HF	RF	HF	RF	HF
0	0	0	0	0	0	1	1	1	1	1	0

where 0 indicates missing data. From Table E. 2, however, values for the missing cells could be determined by associating factor level combinations with alternatives. Thus, the value for alternative 2 was entered not only in the cell associated with the super subject data set (data set 2) but also in the cell associated with the personal data set (data set 1), and so on. The same procedure was followed for each subject-route combination. The final results appear in Table E. 5.

Now, no estimate of the actual amount of error introduced by the missing data procedure is available. However, the possibility for error is indicated by Table E. 1. Moreover, one may infer the types of analyses that should probably be conducted based on the previous discussion of Tables E. 2 through E. 4. Also, one may be guided in his interpretation of results by the same discussion.

First of all, a true indication of differences between subjects can be measured only if one uses the data produced by data set 2 (super subject) since only in this case were both subjects in a subject pair presented with the same

set of alternatives to evaluate. Lack of significance using data set 1 could not be considered to deny the existence of a subject effect. However, a strong subject effect would be indicated by even low-level significance.

Next, it is difficult to measure a data set effect since so much duplication occurs between sets for all subjects and routes. Interpretation of results should be guided by the observations that were made with respect to measurement of a subject effect with data set 1.

Measurement of a true perception model effect can be accomplished only through an analysis of data from subjects 7 and 13 (both data sets) and from subject 11 (data set 2) since only in these cases do the Acid Test Model and Model Three produce no duplications (see Table E.3). However, degradation of the analysis becomes severe only for subjects 8 and 12, especially in the case of data set 1.

The final two main effects (route and attack method) can be studied in any convenient way since no degradation occurs because of missing data. However, an exact analysis of any two-factor interaction would be very difficult to conduct, and with inexact analyses interpretation of such results would be even more difficult.

In the interest of brevity we present, in Figures 9 through 12, a summary of significant results obtained through various analyses of variance. Detailed analysis of variance tables corresponding to this summary appear in Appendix E. Also, plots of marginal means are presented in Appendix E to indicate trends corresponding to most of the significant results. The reader should bear in mind

		SUBJECT					
Source of Variation	Degrees of Freedom	6	7	8	11	12	13
1-Data Set	1		***	**			*
2-Route	3	***	***	***	***	***	**
3-Perception Model	2	***	***	***	***	***	***
4-Attack Mode	1	**		**		***	
12	3			**			
13	2	*	***	***		**	
14	1						*
23	6	***	**	***	***	***	
24	3	*				*	
34	2				*		

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 9.--Summary of Significant Results by Subject

Data Set 1

Source of Variation	Degrees of Freedom	Subject 6	7	8	11	12	13
1-Route	3	***	***	***			
2-Perception Model	2			***		***	*
3-Attack Mode	1	**		*		***	
12	6		**	***		*	
13	3			**		**	
23	2						

Data Set 2

Source of Variation	Degrees of Freedom	Subject 6	7	8	11	12	13
1-Route	3	***	*	***	***	**	
2-Perception Model	2	**	**	***	**	**	**
3-Attack Mode	1			**			
12	6			***	**	*	
13	3					*	
23	2				*		

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 10.--Summary of Significant Results by Subject and Data Set

		Subject Pair	
Source of Variation	Degrees of Freedom	7, 11	8, 12
1-Data Set	1		***
2-Route	3	**	
3-Subject	1	***	***
4-Perception Model	2	**	
5-Attack Mode	1		
12	3		**
13	1		
14	2	**	***
15	1		
23	3		***
24	6	***	***
25	3		*
34	2		***
35	1		*
45	2	*	

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 11.--Summary of Significant Results by Subject Pair

	Data Set	1		2	
Source of Variation	Degrees of Freedom	Subject Pair		Subject Pair	
		(7, 11)	(8, 12)	(7, 11)	(8, 12)
1-Route	3			***	
2-Subject	1	***	***		***
3-Perception Model	2			***	
4-Attack Mode	1				***
12	3		***		***
13	6	**	***	***	**
14	3		***		
23	2		***		***
24	1		***		
34	2				

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 12.--Summary of Significant Results by Subject Pair and Data Set

that the analyses are only approximate because of the steps taken to account for missing data.

In the paragraphs that follow we discuss conclusions to be drawn from Figures 9 through 12 and the associated plots in Appendix E. However, prior to this discussion, let us make some further observations concerning the interpretation of significance. In Figures 13 and 14 are presented plots of a performance measure by subject. This performance measure P is the ratio of sums of squares of error to total sums of squares and may be viewed as a measure of the degree to which the statistical model fits the data. It can be seen that relatively large amounts of unexplained error exist for subjects 11 and 13 considering data set 1 alone, while the same is true for subjects 7 and 13 considering only data set 2. Overall, subjects 11 and 13 exhibited the greatest amount of variability with respect to the model, with subjects 6 and 8 performing best. In any case, with little unexplained variability it takes less factor variability to produce a significant result. Thus, for example, one would expect many significant results from subject 8, especially with data set 1. The summary tables do reveal this trend.

Data Set Effect

As may be seen from Figure 9 the data set effect is significant for half the subjects, and furthermore it interacts strongly with perception model effect for most subjects. Examination of the marginal means in Appendix E indicates that for all subjects except subject 13, alternatives selected by using personal data are preferred over those selected by using super subject data. This difference can be as little as 5% or as great as 15%. However, subject 13 exhibits exactly

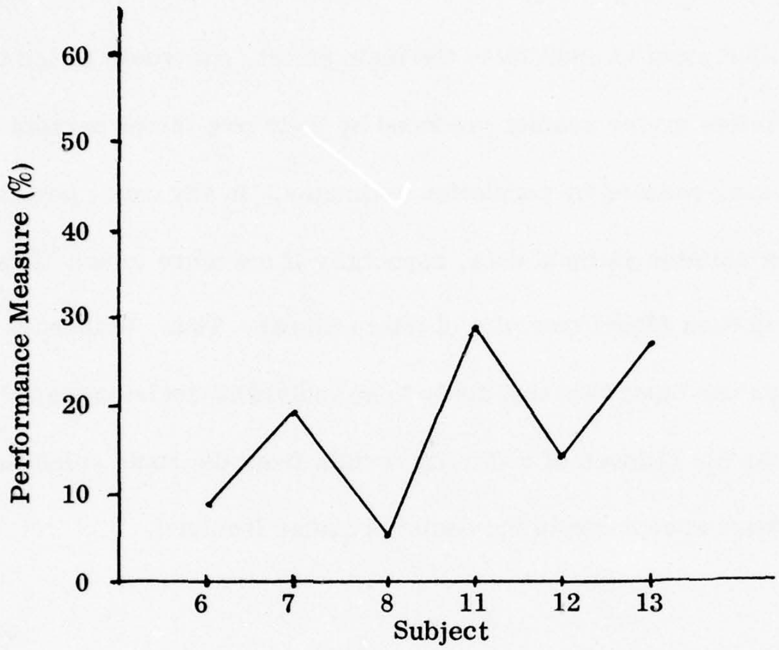

Figure 13. --Plot of Performance Measure by Subject (Combined Data Sets)

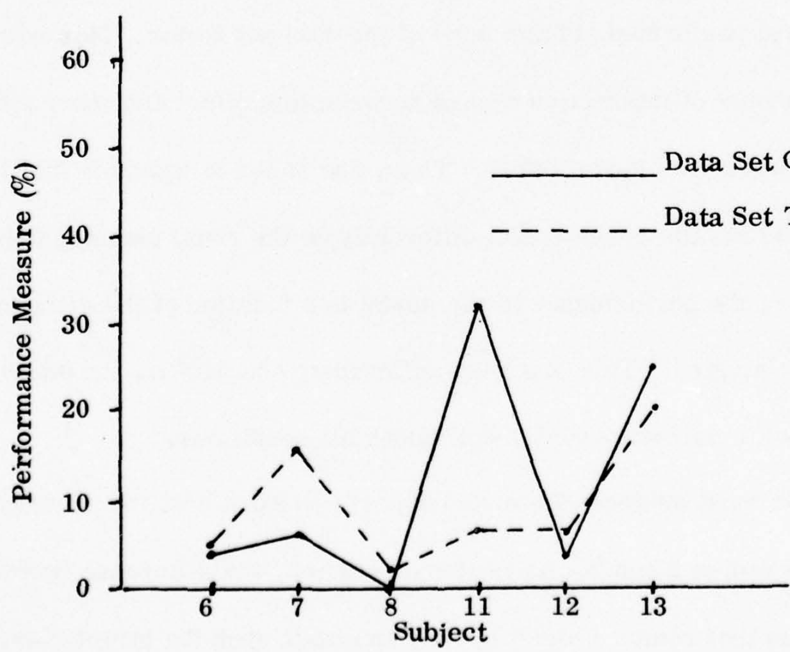

Figure 14. --Plot of Performance Measure by Subject

the opposite trend with over 15% greater preference for data set 2. Considering the interactions that exist in addition to the main effect, one would be led to conclude that most pilots prefer results produced by their own threat perception data as opposed to those produced by population estimates. In any case, population estimates are not suitable as input data, especially if one were to use Model Three or the Acid Test Model (see plot of interactions). Thus, it appears that one should always use input data that apply to an individual decision maker if one wishes to increase his chances of obtaining results from the route selection model that are more acceptable to the decision maker involved.

Route Effect

One of the strongest effects in the experiment is the route effect. In the analysis that includes the data set factor, the effect is significant for all subjects. Furthermore, it is significant for at least half the subjects even when independent analyses are performed at each level of the data set factor. Moreover, a considerable amount of interaction occurs between this effect and other effects, especially the perception model effect. Thus, one is led to conclude that the subjects view the results of the model differently as the route planning task changes. Hence, the performance of the model is a function of the situation in which it is to be applied. This is a very unfortunate conclusion, for one would desire the model to perform equally well under all conditions.

Now, for most subjects the model appears to work best for routes 3 and 4 as opposed to routes 1 and 2. As explained earlier, the difference between these routes was that routes 1 and 2 include an attack upon the target closest to

the left hand side of the battlefield. However, they also differed in that the target to be attacked during execution of these routes was usually the lighter of the two weapons present. Therefore, it would appear that the model performs better with a more lethal weapon as the target, or perhaps the model performs best when the subject percieves the route selection situation to be more difficult. Such a tendency is indicated by the data in Table 5. These data were collected during the first step of Phase II in which the subjects were asked to rank and rate the four route selection situations on the basis of difficulty, with the most difficult route rated 100. One can see that the data correspond generally with the ratings given the route alternatives. However, more investigations are required in this area.

Table 5

Relative Route-Situation Ratings

Subject	Route-Situation			
	1	2	3	4
6	45	89	70	100
7	90	50	75	100
8	20	85	45	100
9	24	47	88	100
10	22	33	89	100
11	62	100	94	94
12	25	62	87	100
13	60	100	40	85
Normalized Average	45	73	76	100

Attack Mode

The attack mode effect seems to be fairly significant with only a relatively small number of interactions occurring with the other factors. It is interesting to note that for the subjects registering a significant effect, running fire route alternatives are preferred to hover fire alternatives. Thus, it may be that the method used in the route selection model to represent running fire is better than that used to represent hover fire. More on this topic will be presented in Chapter 5.

Perception Model

The perception model effect is also one of the most significant effects in the experiment as we had hoped it would be. Unfortunately interactions exist with the route effect and also with the subject effect.

Examination of the marginal mean plots indicates there is a large overall difference between Model One and the other two perception models taken together. From the preceding analysis of missing data, it is understandable why the Acid Test Model and Model Three score so closely together (see Table E.3) in relation to Model One. However, the magnitude of the difference exhibited between Model One and the other two models is pleasantly surprising. One can only conclude that Model One results are evaluated differently by subjects, and from the main effects plot, Model One results are preferred by four of the six subjects. Subject 13 prefers Model Three results while subject 12 prefers either of the other two model results.

Now, the interaction with the route effect causes some problem, but it is not overwhelming. Examination reveals that the model that is preferred by a subject will in most cases continue to be preferred as the routes change, even though a significant interaction exists.

To test the effects of the interaction, a minimax analysis was performed. First, the route-perception model marginal means were averaged across all subjects. The resulting data appear as in Figure 15. A minimax solution suggests that Model One should be adopted in the face of uncertainity with respect to the situation in which the model would be applied. If Model One were adopted the worst result would be an average rating of 56%. However, to choose the Acid Test Model could yield an average rating of 39% while a choice of Model Three could yield an average rating as low as 44%.

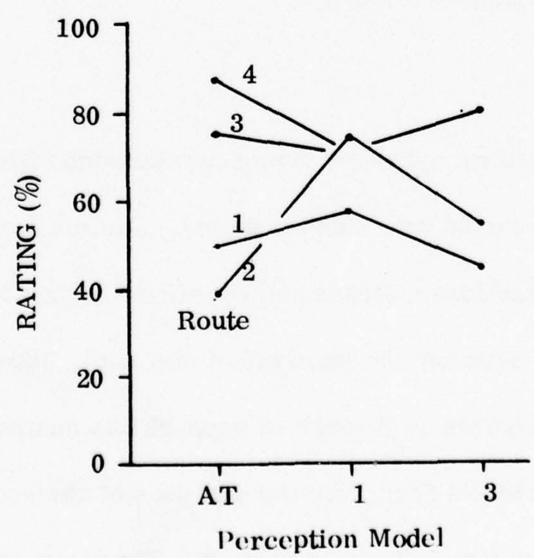

Figure 15.--Perception Model - Route Interaction Across All Subjects

A word of caution should be interjected at this point. To select Model One to the exclusion of the other models could be a foolish decision in the face of the rather sizable perception model-subject interaction. From the marginal mean plots it is known that two of the six subjects preferred a model other than Model One. In fact, we can be only 65% confident that we would please even half the entire Army pilot population possessing the backgrounds of the subjects tested. With different types of training and experience the subjects might view the models in an entirely different fashion. A more prudent approach would be to select Model One as the most promising candidate but to continue experimentation to determine if alterations of the models tested so far can produce better results. At the very least, another subject group with a possibly different background should be tested in an attempt to improve the confidence limit. More on this topic will be presented in Chapters 5 and 6.

Subject Effect

In all the preceding analyses, numerous occasions have arisen in which the subject factor interacted with another factor. Examination reveals that in addition to these interactions a strong subject effect occurred in most of the analyses of variance, although the main effect was not as important as the interactions in general. Figures 16 through 18 support this contention. Here, we have presented a breakdown of the various analyses of variance that were performed in which the subject factor was present. The intent is to show the contribution of subject main effect and subject interactions to overall variation. In particular it is seen that subjects 8 and 12 exhibited basically two different

Subjects 7 and 11

Source of Variation	Degrees of Freedom		Sums of Squares		Percent of Total	
Main Effects	8		35138.37		41.0	
Subjects		1		4280.01		5.0
Other		7		30858.36		36.0
Interactions	24		25972.06		30.4	
Subject		7		2332.30		2.7
Other		17		23639.76		27.7
Residual	63		24524.69		28.6	28.6
TOTAL	95		85635.12		100.0	100.0

Subjects 8 and 12

Source of Variation	Degrees of Freedom		Sums of Squares		Percent of Total	
Main Effects	8		18070.95		17.8	
Subject		1		8990.01		8.9
Other		1		9080.94		8.9
Interactions	24		66735.84		65.8	
Subject		7		47372.38		46.6
Other		17		19363.96		19.2
Residual	63		16624.96		16.4	16.4
TOTAL	95		101431.75		100.0	100.0

Figure 16.--Subject Effects and Interactions
(Combined Data Sets)

Subjects 7 and 11 (Data Set 1)

Source of Variation	Degrees of Freedom		Sums of Squares	Percent of Total	
Main Effects	7		13499.07	40.3	
Subject		1	4485.33		13.4
Other		6	9013.74		26.9
Interactions	17		11640.43	34.7	
Subject		6	3132.76		9.3
Other		11	8507.67		25.4
Residual	23		8378.36	25.0	25.0
TOTAL	47		33517.85		

Subjects 7 and 11 (Data Set 2)

Source of Variation	Degrees of Freesom		Sums of Squares	Percent of Total	
Main Effects	7		23768.13	47.1	
Subject		1	652.69		1.3
Other		6	23115.44		45.8
Interactions	17		15696.52	31.2	
Subject		6	1875.07		3.7
Other		11	13821.45		27.5
Residual	23		10928.27	21.7	21.7
TOTAL	47		50392.89	100.0	100.0

Figure 17.--Subject Effects and Interactions
by Data Set (Subjects 7 and 11)

Subjects 8 and 12 (Data Set 1)

Source of Variation	Degrees of Freedom		Sums of Squares	Percent of Total	
Main Effects	7		13647.61	25.1	
Subject		1	4275.19		7.9
Other		6	9372.42		17.2
Interactions	17		37346.77	68.7	
Subject		6	28312.87		52.1
Other		11	9033.90		16.6
Residual	23		3353.55	6.2	6.2
TOTAL	47		54347.90	100.0	100.0

Subjects 8 and 12 (Data Set 2)

Source of Variation	Degrees of Freedom		Sums of Squares	Percent of Total	
Main Effects	7		8561.12	18.5	
Subject		1	4720.33		10.2
Other		6	3840.79		8.3
Interactions	17		29243.98	63.4	
Subject		6	21318.06		46.2
Other		11	7925.92		17.2
Residual	23		8348.77	18.1	18.1
TOTAL	47		46153.84	100.0	100.0

Figure 18.--Subject Effects and Interactions by Data Set (Subjects 8 and 12)

modes of decision behavior. Further examination of many of the marginal mean plots shows that subject 12 acts in a manner very similar to subject 13, while subject 8 performs as subjects 6, 7, and 11. Thus, we are led to conclude that at least two and possibly more basic modes of decision behavior may have existed within the subject group. If this were found to actually be the case in general, then any hope of developing one descriptive route selection model that would be universally applicable to all helicopter pilots would be dashed. Also, such a finding would possibly possess widespread implications. For example, the philosophy of combat operations simulation design would be changed drastically. Furthermore, if some of the modes of behavior could be demonstrated to be in some way undesirable, then Army training programs or pilot screening procedures might need to be revised. Unfortunately the limited experimentation that has been conducted does not permit strong statistical statements in this area.

Worth of the Model

As has been seen, the rating given to the route selection model by the subject group varies in a very complex way with almost every factor included in the analysis. However, some very gross observations may be made with respect to the overall worth of the model as viewed by the decision makers. Figure 19 shows the rating of the route selection model as a function of the perception model used, for two different classes of decision makers (those preferring Model One, those not preferring Model One) as well as for all decision makers. The effects of all other factors have been averaged. Recalling that the ratings were:

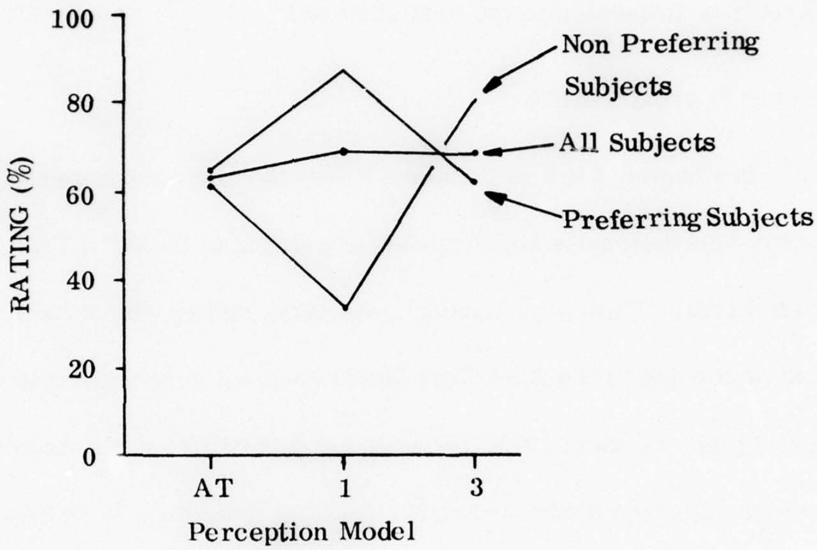

Figure 19.--Overall Model Rating

100: equivalent to decision maker's route plan,
95-99: decision maker's plan preferred, but no reason can be given for preference,
70-94: decision maker's plan slightly preferred, with reason, and
0-69: decision maker's plan strongly preferred with reason.

Thus, among subjects preferring Model One, the decision maker's plan was only slightly more preferable than the route selection model alternatives. However, this same model would be rejected strongly by those subjects preferring one of the other models. The same observations can be made about the Acid Test-Model Three combination. However, if one were to try to please everyone with

just one model, then on the average exactly the opposite effect would be achieved. This observation is in agreement with observations made earlier and more on this topic will be presented in the next chapter.

Effect of Approximations

In Chapter 3 it was pointed out that the route selection model as it exists can only approximately select routes according to the Acid Test Model of perceived threat. This is so because a decision maker who actually perceives threat according to the Acid Test Model does not perceive route segment threats in an additive manner. That is, segment disutilities are not additive. To revise the route selection model to account for this deficiency is beyond the scope of the present research. However, the inadequacy of the route selection model may in part account for the poor showing of the Acid Test Model. Unfortunately, at this point there is no way to determine to what degree the Acid Test Model results have been degraded.

It is also true that the route selection model can only approximately select routes according to Model Three. This is so if a route segment intersects the circle defining the maximum perceived effective range of an enemy weapon. For example, in Figure 20, a route segment of duration t has its midpoint inside the circle. Assuming only the one weapon in the scenario, perceived threat is simply t. However, if the segment were divided at its midpoint into two subsegments as shown then the perceived threat would be $.001\, t_1 + t_2 = .5005\, t$

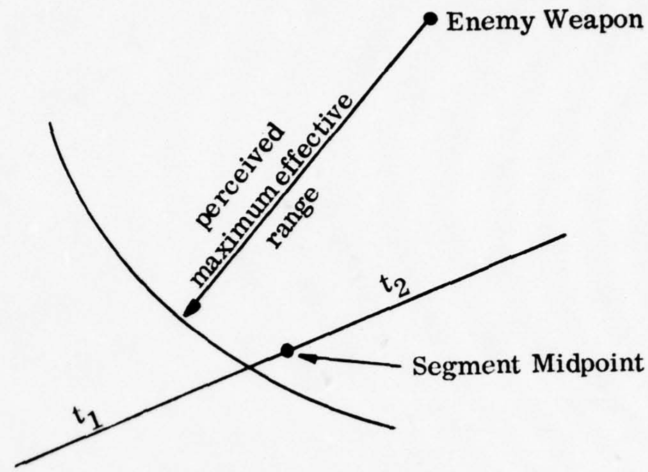

Figure 20.--Model Three Degeneracy

Thus, the perception of threat predicted for route segments by Model Three is dependent upon the layout of the convex areas whose boundaries form route segment end points. Instead of the rather arbitrary approach that was taken in structuring the route selection environment (see Appendix A), care should have been exercised to approximate the maximum threatening range boundary with edges of convex areas. Then route segments would terminate on the threatening boundary instead of intersect it. Unfortunately, to take such care, tailoring the representation to each subject would have been prohibitively time consuming and costly.

CHAPTER 5

RESEARCH EXTENSIONS TO THE FORT RUCKER EXPERIMENT

By Don C. Hutcherson

Introduction

The reader will recall from Chapter 1 that one of the purposes of this research is to determine whether or not decision and value-theory concepts can be used as elements of a model to explain the behavior of a military decision-maker in a helicopter route planning task. Considering the results presented in Chapter 4 it is not apparent that the question has been completely resolved.

First, it was discovered during the Phase I Experiment (Chapter 3) that considerable variation exists between subjects, not only with respect to such topics as the speed that is to be employed during an attack, but also with respect to perceptual topics such as the relative threat ratings that are given to a set of enemy weapons. Even though all the subjects were presented the same information during the experiment they either perceived the information differently or they were operating on different sets of preconceived notions developed individually or perhaps in groups.

Now, such a finding is not bad in itself since the hypothesis had been made at the start of the research program that the population of pilots might very well be heterogeneous; the experiments had been designed to test this hypothesis. However, during the Phase II Experiment it was discovered that heterogeneity

apparently carries over even into the methods used by pilots to select routes. For example, a highly significant subject-perception model interaction was found to exist. Moreover, four of the six subjects apparently preferred routes determined by the route selection model employing Model One to measure perceived threat. These subjects as a group found their own routes to be only slightly more preferable overall than the routes selected by the computer using Model One. However, the same model was rejected strongly by the other two subjects. These subjects much preferred routes selected by using either Model Three or the Acid Test Model.

The net result of the above heterogeneity is that it may be impossible to develop a single route selection model that is completely acceptable to all pilots. Even if the model were designed to accept personalistic input data from individual pilots it still might not produce results that are acceptable to all individuals. Thus, two or more route selection models may be required.

Another result of the Phase II Experiment is that the acceptability of the computer prepared routes was not as high as had been hoped for generally. Overall, the six subjects rated the computer routes as being less that 70% as good as their own, which translates into the following qualitative statement (using the rules of Chapter 4): the decision-maker strongly prefers his routes to those prepared by the model and can state definite reasons for his preference. Even if the average rating for Model One is determined by using only the ratings from the four subjects who apparently preferred Model One results, a value of less than 90% is obtained. This translates into the statement that the decision-

maker only slightly prefers his own route plan, but again a reason can be cited for the preference.

All of the observations cited above lead to the conclusion that further analysis and experimentation are required to obtain a better understanding of the route selection decision process. The remainder of this chapter is devoted to a discussion of a first step that has been taken in this direction.

First, analyses will be described that were conducted in an attempt to isolate those factors that were instrumental in the subjects' rejection of the computer prepared routes in favor of their own routes. Then, modifications that were made to the route selection model in an attempt to obtain routes of higher acceptability will be described. Next, an experiment will be discussed which had two objectives. First, the experiment was conducted to determine whether or not the modifications to the route selection model had had any effect on the acceptability of the model's routes. Second, the experiment was conducted to determine if a second indication of population heterogeneity could be obtained, and if so, whether the second indication was consistent with the first. Finally, an analysis of the results of the experiment will be presented along with conclusions that were drawn from the analysis.

Analysis of Rejection Factors

The fact that several of the subjects participating in the Phase I and Phase II Experiments consistently displayed a high degree of enthusiasm for their tasks turned out to be extremely important to the analysis of factors leading to rejection of some of the route selection model results. First, these

subjects submitted copious notes to explain their reasons for rejecting computer routes they judged to violate one or more of their route selection criteria. An example of some of these notes appears in Table 6.

Next, the subjects were very conscientious in completing a written critique of the experiment that was administered at the end of the first experimental session, immediately after the route selection exercise. While the critique covered a variety of topics, responses to questions related to the route selection decision process turned out to be especially helpful in the analysis of rejection factors. A detailed summary of responses to all questions in the crituque appears in Appendix F at Exhibit F.1.

Finally, additional insight was obtained from responses to one of the questions contained on the Master Information Form which was completed during the Phase I Experiment. This question was concerned with the factors that each subject considered in deciding the mode of fire (running fire or hover fire) he would employ during a given attack. A summary of responses to this question appears in Table 7.

In analyzing material that relates to the overall route selection decision process in Table 6 and Exhibit F.1, it is difficult to isolate anything in particular that would cause the subjects generally to reject route selection model results. In fact, the subjects apparently agree with many of the assumptions that were made in developing the route selection model in general and with the assumptions of Model One as a threat perception model in particular. In summary, the subjects state that they choose their routes to minimize exposure to enemy

Table 6

Summary of Notes on Rejection Criteria

This route approaches within the effective range of the supporting weapon.

There is no need to engage in a running fire duel when a covered route to a hover fire position is available.

I would never select a hover fire position that requires an exposed approach to the position.

This route does not use the terrain as well as my route.

In order to fire from the indicated firing position one would have to climb too high. This means the aircraft would be exposed too long and would be silhouetted when the firing position is achieved.

The hover fire position is too close to the target.

Running fire in this situation results in too much exposure.

This route takes a short cut that is exposed.

Table 7

Summary of Responses Regarding Factors
Leading to a Choice in Attack Mode

Attack Mode	Factors Cited
Hover Fire	Masking available during approach to firing position. Minimum exposure to target weapon. Minimum exposure to supporting weapon. Avoids being silhouetted against the sky. Outside target's effective range. Outside supporting weapon's effective range. Permits engagement at maximum range of my weapon. Targets are hard to detect during running fire. Permits fire as soon as range is "right."
Running Fire	Attack must be conducted inside target's effective range. No masking terrain available. The enemy cannot hit a moving target as well as a stationary target. Launch range is too close for hover fire. Minimum exposure time. Avoids being silhouetted against the sky. Allows movement to masked area while missile is still in flight.

weapons and maximize the element of surprise during an attack. During enroute travel they fly as close to the ground as possible and will go to any length to avoid being intervisible with the enemy. If intervisibility is unavoidable they try to choose a path that is as short as possible and as far as possible from the enemy weapon. For some, even an exposure time that is less than the reaction time of the enemy weapon is considered dangerous.

Proceeding further in the analysis of material in Tables 6 and 7 and Exhibit F.1, one finds that the subjects apparently have very definite and fairly consistent criteria for selecting a mode of fire (running or hover) to employ in a given tactical situation. The same can be said for the criteria they use in selecting a firing position. For example, the subjects apparently favor hover fire over running fire unless they are forced into a duel by some factor such as terrain (lack of covered approaches) or weapon effective range (their own versus the enemy's). They apparently would prefer to deliver fire from a hover fire position outside the range of the enemy weapon if possible. Furthermore, in choosing a hover fire position they seek a masked avenue of approach from which they may "pop up" to fire. However, they try to avoid being silhouetted against the sky from this position.

Now, it is in this area that there may be some problems with the route selection model. It is obvious that the subjects considered the selection of a mode of fire and a firing position to be one of the most important aspects of the route selection task. Yet, it should be obvious that, to this point in time, the research program has not been directed specifically toward an analysis of the

decision process involved in the selection of a mode of fire. Furthermore, as explained in a subsequent paragraph, the procedures used in the model to represent the selection of a firing position are fairly simple, and it is possible that they may be at odds with the actual decision process.

In the remaining paragraphs of this section, attention will be directed first to a review of the procedures used in the route selection model to represent the selection of a firing position. Then, a discussion of modifications to the model that have been made to better represent the fire position selection process will be presented. Next, the mode of fire decision process will be discussed in detail, and a procedure, in the form of a hypothesis, will be proposed to predict the mode of fire that a subject will select in a tactical situation of the type that was analyzed during the Phase II Experiment. Finally, an analysis will be performed to determine whether there is any relationship between the mode of fire that a subject selects and the way he views the route selection model results.

Fire Position Procedures. The reader will recall from Chapter 2 that routes constructed by the route selection model consist of five phases. The first is an enroute or approach phase conducted at tree top level (knap of the earth) from a specified starting position to the vicinity of the target. This phase consists of one or more straight line segments connected to form a continuous route. The next three phases are associated with an attack upon the target, with each phase consisting of a single straight line segment. The first segment represents a

transition from the approach route into a firing position and is followed by another segment to represent the firing activity. The final attack segment represents a transition into the escape phase of the mission. The escape phase is similar to the approach phase in that it is conducted at tree top level and consists of one or more connected straight line route segments. The route terminates at a specified boundary of the battlefield.

Now, the segment chosen to represent the firing activity is actually only one of a number of segments that could have been chosen for the route. In preparing each route selection problem for execution a series of equally spaced rays extending outward from the target is constructed to define the directions from which attacks could be conducted. Then a series of points is placed at equally spaced intervals along each attack ray to represent the points at which the firing activity might commence. Finally, there is associated with each of the firing position points another point at which the attack might terminate (upon impact of a missile that has been launched). Any given pair of points forms the endpoints of a possible firing activity segment. The route selection model simply determines a route that contains one and only one of the possible firing activity segments. The segment chosen is the one that permits a route of minimum perceived threat to be constructed. (See Chapter 2.)

Now, a basic requirement of the model is that one must be able to determine the perceived threat associated with any given route segment. Furthermore, regardless of the perception model used, the perceived threat associated with a route segment is calculated in different ways depending upon

whether or not the segment is intervisible with an enemy weapon. (See Chapter 3.) Thus, one must always be able to specify the intervisibility condition that exists on a segment.

For the enroute phases of the mission this requirement poses no problem since these phases are conducted at tree top level, and intervisibility conditions for this mode of flight are specified at all points on the battlefield by a line of sight map. (See Appendix A and Chapter 2.) However, there is a problem in specifying intervisibility relationships for the three segments comprising an attack. First, it is obvious that the firing activity segment is intervisible with the target since the existence of a line of sight has been specified as a condition for an attack. However, without calculation, it is impossible to determine whether this segment is intervisible with other weapons on the battlefield.

Next, the transition segments may involve vertical movement in relation to the terrain, either a climb to a firing position or a dive after the firing activity. Thus, a highly dynamic situation exists on these segments with respect to intervisibility. Again, nothing can be determined about the actual conditions that exist without calculation.

To simplify procedures in the route selection model it is assumed, for computational purposes only, that the transition segments of an attack are conducted at tree top level. Thus, the intervisibility conditions that exist on these segments can be determined by the same procedures that are used to determine conditions along any of the enroute segments of the mission. Furthermore, it is assumed that the firing activity segment is fully exposed to all enemy

weapons on the battlefield. These two assumptions permit very rapid evaluation of the perceived threat associated with attack segments. Moreover, at the time the assumptions were made it was felt that they would be fairly representative of the way in which the pilots actually attempt to conduct an attack and the way in which they view the intervisibility situation. As will be discussed below, there evidently is reason to doubt these assumptions.

Model Modifications. In examining the material in Tables 6 and 7 and Exhibit F.1, there are several comments from the subjects which lead to the following general conclusions. First, if hover fire is being contemplated the firing position is evidently selected in such a way that the route leading to the position is completely covered with respect to all enemy weapons. Otherwise, hover fire will not be used. Next, hover fire is apparently conducted from a position that is at or near the maximum effective range of the ordnance being used; and hopefully this position is outside the range of the target's weapon. Finally, some of the subjects evidently recognize that in climbing to a firing position, there is a good possibility that the transition segment may be exposed to other weapons on the battlefield. Furthermore, the exposure time involved may be quite large since some firing positions must be highly elevated above the terrain to achieve a line of sight with the target.

From the previous discussion of the firing position selection procedures, it is obvious that there are descrepancies between the procedures used in the route selection model and the methods used by the subjects. Therefore, the

model procedures have been modified in an attempt to represent the decision behavior of the subjects better.

First, routes involving hover fire are constructed to insure that the approach to a firing position is as covered as possible. To accomplish this objective, the model has been modified to exclude, as a candidate firing position, any hover fire position that is located over an area of the battlefield in which a knap of the earth flight profile would be exposed to any enemy weapon.

Second, a procedure has been adopted to account for the increased exposure that may result from a highly elevated firing position. The procedure assumes that the firing activity segment is exposed to all enemy weapons on the battlefield and that the transition segments are conducted at tree top level. Thus, the basic procedure remains unchanged. However, two increments of time are added to the exposure time associated with the firing activity route segment. The first increment is intended to account for the time that would be required to climb to the firing position from a knap of the earth flight level. The second increment is intended to account for the time that would be required to dive from the firing segment back to a knap of the earth flight level. Thus, the perceived threat computed for the firing activity segment effectively comprehends increases in threat arising because of exposed climbs to and dives from a firing position.

The procedure used to compute the exposure increments is as follows:

1. Determine the elevation of the firing (exit) position.
2. Determine the elevation of a knap of the earth flight level at the firing (exit) position.

3. Determine the climb (descent) required.

4. Compute the exposure time increment to be added based on a standard military rate of climb.

The reader will note that nothing has been done to force the selection of a firing position at the maximum effective range of the weapon. Except for the points excluded as a result of the procedure outlined in a previous paragraph, the candidate firing positions are determined as before.

The reason that this step has not been taken is that the model is still based upon the following fundamental proposition: From a set of all feasible route alternatives, the decision maker chooses that route which possesses minimum perceived threat. The set of alternatives originally considered feasible by the model has been reduced to some degree by ruling out hover fire positions that involve exposed approaches to these positions. However, it has been decided to reduce the feasible set no further until additional experiments can be conducted to determine whether or not such reductions are required.

Firing Mode Decisions. It has been stated that the subjects apparently favor hover fire over running fire unless they are forced into a running fire duel with the target by some factor such as the terrain (lack of covered approaches) or weapon effective range (their own versus the enemy's). This conclusion is formed largely from the statements summarized in Tables 6 and 7 and Exhibit F.1.

However, there are probably additional factors which also influence the decision. For example, it is quite likely that individual style and experience

are important factors. In fact, considering previous results, it would be very surprising to find that the population of decision makers is homogeneous in the way it formulates the mode-of-fire decision. One subject even stated that he had had no occasion in combat to select one mode of fire over another.

Unfortunately, there are no data available with which to perform precise statistical analyses of the factors influencing the mode-of-fire decision. The factorials employed in the Phase II Experiment were developed to permit analyses of the factors affecting the overall predictive performance of the route selection model. In particular, the analyses were directed at evaluating the three proposed threat perception models. The mode-of-fire decision process was not a specific concern of the experiment.

However, there are some quantitative data available which may be analyzed to a degree. Furthermore, they tend to confirm the general conclusions stated earlier which were formed on the basis of qualitative statements advanced by the subjects.

Table 8 reveals the mode of fire selected in each route selection situation analyzed by the subjects. In addition, the target weapon, the supporting weapon, their position numbers (see Appendix A), and the intervisibility condition (with respect to the target weapon) that existed at the start of the route are also shown.

First, it may be seen that out of the twenty-four cases, the subjects selected hover fire fifteen times (62%). While this is not a particularly high frequency, the fact that it is greater than fifty percent still could be construed

Table 8

Mode of Fire Selection Data

Subject	Situation	Target Weapon		Supporting Weapon		Initial Intervisibility Condition	Mode of Fire Selected
		Type	Position No.	Type	Position No.		
6	1	1	1	2	2	U	H
	2	1	1	2	2	E	H
	3	2	2	1	1	U	H
	4	2	2	1	1	E	R
7	1	1	3	2	4	U	H
	2	1	3	2	4	E	H
	3	2	4	1	3	U	H
	4	2	4	1	3	E	R
8	1	1	3	2	5	U	R
	2	1	3	2	5	E	R
	3	2	5	1	3	U	R
	4	2	5	1	3	E	R
11	1	1	3	2	4	U	R
	2	1	3	2	4	E	H
	3	2	4	1	3	U	H
	4	2	4	1	3	E	H
12	1	1	3	2	5	U	H
	2	1	3	2	5	E	H
	3	2	5	1	3	U	R
	4	2	5	1	3	E	R
13	1	2	4	3	5	U	H
	2	2	4	3	5	E	H
	3	2	5	3	4	U	H
	4	2	5	3	4	E	H

Legend

Weapon Type 1 - 14.5 mm
2 - 23 mm
3 - Redeye

Initial Intervisibility Condition: U - unexposed to target weapon; E - exposed to target weapon

Mode of Fire Selected: H - hover fire; R - running fire

as evidence of a preference for hover fire. Unfortunately, the probability of achieving at least this frequency even if the choice of firing mode were random is 0.20. Thus, the evidence is not statistically overwhelming.

Now, there are no data in Table 8 to precisely reveal the effects that terrain and weapon effective range have on the choice of firing mode. Each situation is very complex, involving two weapons with different effective ranges located at two distinct positions. Furthermore, a high degree of confounding exists with respect to the weapons and positions involved as the subject and/or the situation factor level changes. However, an indication that terrain and weapon effective range do affect the choice of firing mode is evident in the data. For example, in situations involving a 14.5 mm target weapon, seventy percent of the cases represent hover fire choices (7 out of 10 cases). On the other hand, routes directed at a 23 mm target weapon result in hover fire only fifty-seven percent of the time (8 out of 14 cases). If the analysis is further restricted to consider only those routes that start from an exposed position, the incidence of hover fire increases to eightly percent (4 out of 5 cases) when the target is a 14.5 mm weapon, and decreases to forty-three percent (3 out of 7 cases) when the target is a 23 mm weapon. An explanation for these data trends lies in the fact that a 14.5 mm weapon has an effective range of 1400 meters as opposed to a 3000 meter range for the 23 mm weapon. The subjects evidently felt they could deliver fire from a hover fire position outside the range of the 14.5 mm weapon more often than they could against a 23 mm weapon.

Evidence of heterogeneity among the subjects is also available from the data in Table 8. First, the reader will recall that the subject pairs (7, 11) and (8, 12) were confronted with identical route selection situations. Yet, in both cases the subject pairs disagreed on the mode of fire to be employed in fifty percent of the situations. Furthermore, subject 8 chose running fire in all situations. Such a performance appears to be different from that of the other subjects.

Firing Mode Prediction. Given the observations in the preceding paragraphs and considering previous conclusions based on qualitative evidence, it is obvious that there are factors such as terrain, weapon effective range and individual subject performance that do affect the choice of a mode of fire. Thus, an experiment could be designed to yield data on these relationships. However, for our purposes it is not clear that such an experiment would be entirely justified. That is, it may not be so important that detailed knowledge of the mode-of-fire decision process be acquired. Rather, it is probably more important that it be possible to use the route selection model to predict the mode of fire that a decision maker would employ in a given situation. Therefore, in the following paragraphs a procedure is proposed that may produce the desired result. The validity of the precedure is testable, and in fact, has been tested as will be explained in the analysis section of this chapter.

The reader will recall that the route selection model is designed to determine a route that includes either a hover fire or a running fire attack upon the target. The type of attack to be included is specified beforehand.

Furthermore, any route that is selected has the property of minimum perceived threat, where threat is as measured by one of the three threat perception models developed in Chapter 3.

Now, the procedure proposed for using the route selection model to predict the mode-of-fire decision in a particular tactical situation is as follows: Using a given threat perception model, determine a route that includes a hover fire attack. Denote the overall threat of the route as T_{HF}. Repeat the analysis for a running fire route to obtain T_{RF}. If $T_{HF} < T_{RF}$, then predict that the decision maker will prefer the hover fire route result. Otherwise, predict that the decision maker will prefer the running fire route result.

Obviously, a major assumption of the above procedure is that the decision maker is guided in his mode-of-fire decision by the same set of principles that he uses in selecting other portions of his route. Translated into terms used to develop the route selection model, the decision maker simply acts so as to minimize perceived threat. Thus, it is necessary only to determine the perceived threat of two alternative courses of action. The alternative that is selected is the one that minimizes perceived threat. Of course, it is still assumed that the procedures used to evaluate the perceived threat of other portions of the route can be used in evaluating the perceived threat of the attack phase. This assumption has applied without exception throughout the entire research program. If specialized procedures are required, then the modeling approach needs to be revised. Further experimentation will yield information regarding this possibility.

There are several difficulties that may arise in applying the mode-of-fire decision procedure that has been outlined. These difficulties should be discussed at this point to avoid problems later. First, it is possible that inconsistent results may be obtained from the three threat perception models. That is, the procedure might predict that the hover fire route result is preferable to the decision maker when threat is measured by one of the three threat models, but that the running fire route result is preferable when another threat model is used. Therefore, it is proposed that the procedure can be applied with total validity only after the threat perception model which applies to a given decision maker has been determined. Furthermore, the true threat perception model for a particular decision maker may not even be one of the three models under consideration.

Another problem lies in the fact that the procedure does not predict with certainty. Even if it were known with certainty that the route selection model structures a route by exactly the same procedures used by a decision maker, the intrapersonal variation of the decision maker might yield different rankings for the route selection model results in repeated trials of the same decision problem. Thus, the procedure can predict only the most probable ranking of the model results.

Finally, another problem related to the one just outlined is that the procedure may not predict the mode of fire that a decision maker actually selects in a given situation. Even if the model were to perfectly duplicate the processes

involved in the mode-of-fire decision, the intrapersonal variation of the decision maker would rule out prediction with certainty. The procedure could predict only the most probable firing mode decision.

To compound the problem still further, there remains a considerable amount of uncertainty about the model itself. To this point in time there is no guarantee that the route selection model perfectly duplicates the decision processes of the decision maker. Any disparity that exists could reduce the effectiveness of the proposed mode-of-fire prediction procedure.

A Note on Ratings. The thrust of this section has been to isolate those factors which may have contributed to a poorer than expected acceptance of route selection model results during the Phase II Experiment. Changes to the model have been proposed to better represent the selection of a firing position, and a procedure has been developed to predict the firing mode that a decision-maker will select in a given situation.

However, it is suspected that another factor is present which may also contribute to the apparently poor showing of the route selection model. This factor could be more important than any other factor considered so far, and if it is present it might be extremely difficult to deal with. It is suspected that the subjects are actually biased against the route selection model results, either because they are unable to accurately judge the relative "goodness" of a route alternative or because they subjectively reject a route that employs a firing mode different from the mode they used in the same situation.

An indication of this latter type of bias is reflected by the data in Table 9. This table shows the mode of fire selected for each situation faced by the subjects during the Phase II Experiment. Also shown are the average ratings given to the hover fire and running fire routes produced by the route selection model. As anyone can see, some of the subjects apparently gave higher ratings to model routes if they happened to include a mode of fire that corresponded to the mode selected by the subject. Overall, sixty-four percent of the ratings (14 out of 22 cases) reflect this tendency.

Also, the data reveal that the subjects are not necessarily biased against just the hover fire routes or just the running fire routes. Such a result would not be indicative of bias. Instead it would indicate some shortcoming in the method used to represent hover fire or running fire.

Now, an experimental technique required to reduce the type of bias outlined above would be to somehow conceal from the subject the identity of his own route during an evaluation of the model routes. Another technique would be to develop some rating procedure for the route selection model results that does not involve selection of routes by the subjects. However, it is difficult to see how the performance of the model could be measured unless some benchmark were available to serve as a reference. More on this topic will appear in Chapter 6.

The other type of bias mentioned above may also affect the apparent acceptability of the model results. This bias is related to the subjects' ability to actually judge the relative "goodness" of two different route alternatives.

Table 9

Indication of Bias

Subject	Situation	Firing Mode Selected*	Average Rating	
			Running Fire	Hover Fire
6	1	H	0	0
	2	H	0.20	0.20
	3	H	0.69	0.48
	4	R	1.05	0.78
7	1	H	0.82	0.95
	2	H	0.63	0.68
	3	H	0.94	0.97
	4	R	0.99	0.98
8	1	R	0.60	0.46
	2	R	0.89	0.85
	3	R	0.93	0.92
	4	R	0.94	0.89
11	1	R	0.72	0.62
	2	H	0.51	0.57
	3	H	0.90	0.88
	4	H	0.70	0.84
12	1	H	0.91	0.57
	2	H	0.83	0.61
	3	R	0.57	0.38
	4	R	0.51	0.57
13	1	H	0.52	0.39
	2	H	0.33	0.32
	3	H	0.80	0.59
	4	H	0.47	0.84

* Hover Fire - H
Running Fire - R

AD-A045 094 OHIO STATE UNIV COLUMBUS SYSTEMS RESEARCH GROUP F/G 1/2
THE HELICOPTER ROUTE SELECTION MODEL (DYNFLITE). (U)
AUG 76 G M CLARK, D C HUTCHERSON, D C BITTERS DAAG25-70-C-0311
UNCLASSIFIED RF-2978-FR-76-4(0) NL

3 OF 6
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For example, a subject might feel that a particular firing position is rather poor because of the amount of exposure time that would be required in firing from the position. Yet, detailed analyses could reveal that the actual amount of exposure time would be less for the route in question than it would be for some other route judged to be superior. Perceptual problems such as these became evident in the comments recorded by the subjects during the route evaluation session of the Phase II Experiment (see Table 6).

To alleviate perceptual difficulties, it is possible to develop a large number of quantitative descriptors of any route selected by the route selection model. For example one might compute the following data:

Total route length
Total travel time
Total exposure time
Range to the target from the firing point
Range to the target at the time of missile impact
Altitude of the firing position
Exposure time during the attack

Such data could then be used in conjunction with a sketch of the route to formulate a more valid opinion. In fact, as will be explained in subsequent sections of this chapter, the route selection model has been revised to prepare data such as those outlined above, and subjects have been given the data to aid in evaluating route alternatives.

The net result of bias is that the route selection model may produce routes that are actually more acceptable to the subjects overall than is indicated by the Phase II Experiment rating data. In evaluating the validity of the model one must be very careful to correct for this bias during analyses, or to revise the

experimental procedure to eliminate it in the first place. The characteristics of some of these procedural revisions have been outlined in previous paragraphs and will be discussed again later in this chapter and in Chapter 6.

The Trial Two Experiment

Given the results of Chapter 4 and the findings of the previous section, it is obvious that there is a need for further experimental investigations into the route selection decision process. First, there is a need to determine whether the modifications to the fire position selection procedure have had any effect on the overall acceptability of the route selection model results. Second, there is a need to determine whether additional indications of population heterogeneity, similar to those discovered in the Phase II Experiment, can be obtained. Finally, there is a need to determine whether or not the proposed procedure for predicting the mode-of-fire decision is valid. Throughout such experiments, it is desirable that procedures be employed to eliminate as much of the bias discussed in the preceding section as possible, subject to time and funds available.

To this end, another experiment has been conducted which was similar in content and approach to the Phase II Experiment. In fact, the subject population used was the same population employed during the Phase II Experiment, with the exception of subjects 9 and 10 whose data were not analyzed for the reasons discussed in Chapter 4. The experiment will be called the Trial Two Experiment in the remainder of this chapter.

Because of time and funds available, the Trial Two Experiment had to be conducted by mail. This meant that the experiment was constrained to use the subject group employed during the Phase II Experiment since it would have been almost impossible to familiarize new subjects with the concepts involved without personal contact. Also, the Trial Two Experiment had to be kept simple, with as few departures as possible from the procedures used during Phase II. This constraint was necessary because of the reduced ability to introduce new concepts and to communicate intricate instructions via the mails. Finally, it was considered desirable to keep the experiment as small as possible in order to assure that the subjects would cooperate in completing the experiment in a reasonable amount of time.

The net result of the constraints outlined above is that it was impossible to achieve all of the desired objectives with the Trial Two Experiment. First, in reducing the size of the experiment, not all the data from the Phase II Experiment were reproduced by the Trial Two Experiment. Not only did this prohibit a direct comparison of all data from the two experiments, but it also reduced the amount of information produced by the Trial Two Experiment.

Next, it was considered impossible to introduce new procedures that would entirely eliminate the subject bias discussed previously. While it was possible to modify the route selection model to produce quantitative descriptors of each route to be used in conjunction with a route sketch during the route evaluation exercise, it was beyond the scope of the experiment to institute procedures that would conceal the identity of a subject's route or otherwise

eliminate the need for a reference route. Thus, procedures to eliminate only a portion of the possible subject bias were available.

Experimental Design. With the exception of size, the design of the Trial Two Experiment was almost identical to that of the Phase II Experiment. Therefore, only a summary of the new design will be presented. For a more thorough explanation of the design the reader should consult Chapter 4.

The overall Trial Two experimental design consisted of four independent complete factorial experiments, of which two were four factor experiments and two were three factor experiments. The previous design had consisted of two five factor experiments and two four factor experiments. However, a blocking factor was eliminated from all four factorials for the Trial Two Experiment. This factor had been included originally to permit an analysis of the effect that input data in the form of population averages would have on the acceptability of route selection model results. It was found in Chapter 4 that one should always use input data that apply to an individual decision maker as opposed to population averages.

Now, all of the factorials included a qualitative factor M, measured at $m = 3$ fixed levels, to account for a threat perception model effect. In this respect the Trial Two Experiment was identical to the Phase II Experiment. Of course, the three models considered were the Acid Test Model, Model One and Model Three as defined previously.

Another factor included in all factorials was the qualitative factor R to account for a route (or situation) effect. While the Phase II Experiment had measured this factor at $r = 4$ fixed levels, the Trial Two Experiment considered

only two fixed levels. This change was adopted as part of the effort to reduce the size of the experiment.

The situations left in the experiment were those that have been referred to as situation one and situation three. From Table 8 one may determine that these situations are the ones in which the starting point of the route is not exposed to the target weapon. It was reasoned that if any situations were to be eliminated, it would be best to eliminate situations two and four. They were considered artificial by the subjects since no pilot would select a route prior to entry into the battlefield that would result in an exposed initial position. However, elimination of the two routes did reduce the information produced by the Trial Two Experiment.

The final factor that appeared in all factorials was the qualitative attack mode factor A, measured at a = 2 fixed levels. Thus, the Trial Two Experiment was identical to the Phase II Experiment in this respect. Of course, the two attack modes considered were running fire and hover fire.

Now, there was a final qualitative factor S which appeared in two of the factorials but which was absent from the other two. This factor was included to account for inter-subject variability and was measured at s = 2 levels. Furthermore, the subject effect was considered random.

The reader will recall that it had been intended originally to include the subject factor in all four of the Phase II Experiment factorials. In fact, four subject pairs, (6, 10), (7, 11), (8, 12) and (9, 13) were actually processed

through the entire Phase II Experiment. However, it became necessary, as explained in Chapter 4, to exclude from analysis the data collected from subjects 9 and 10. For the same reasons, subjects 9 and 10 were excluded from the Trial Two Experiment. Therefore, both the Phase II and the Trial Two Experiments were identical in their treatment of a subject effect.

To summarize the preceding discussion, the Trial Two experimental design consisted of four independent complete factorials consisting of two (s) x (r) x (m) x (a) factorials and two (r) x (m) x (a) factorials, where the symbols are as defined in previous paragraphs. Each of the four factor experiments required a total of 24 observations while the three factor experiments each required 12 observations. This resulted in a grand total of 72 observations, which represents a sizeable reduction from the 384 observations involved in the Phase II Experiment.

For analysis purposes, a model was assumed that included all main effects and all two factor interactions. However, all three factor and higher order interactions were assumed to be zero. Furthermore, all four factors were considered qualitative, and three out of the four were assumed to produce fixed effects. Thus, the model associated with the Trial Two Experiment is consistent with that of the Phase II Experiment.

Conduct of the Experiment. Much of the groundwork for the Trial Two Experiment had been done during the Phase I and Phase II experimental exercises. First, it was intended that the routes which the subjects had selected during

Phase II continue to be used as reference routes in evaluating route selection model results. Second, the threat perception data collected during Phase I still formed a valid input data set for the route selection model. The only new effort involved in conducting the Trial Two Experiment consisted of the following activities:

1. Revision of the route selection model to incorporate modifications to the fire position selection procedures;

2. Revision of the route selection model so that it would prepare a set of quantitative descriptors for each route selected;

3. Execution of the experimental design with the route selection model; i.e., preparation of a route description for each combination of factor levels considered in the experiment; and

4. Preparation of a mailer for each subject participating in the experiment.

Each of these activities will be discussed in the following paragraphs.

From a previous discussion, the reader will recall that the fire position selection procedures were modified to exclude situations in which the approach to a hover fire position is exposed to the enemy. The procedures were also modified to account for increased exposure time resulting from climbs to elevated firing positions. However, changes to the logic of the model to incorporate these modifications were minimal. By far the more extensive changes were those required to produce a set of quantitative descriptors for each route selected. Extensive bookkeeping procedures were required to accumulate some of the data which were desired as output.

The reader will recall that the descriptors were desired so that a subject asked to evaluate a given route alternative might have available as much objective data as possible. It was hoped that these data would alleviate problems the subjects apparently experience in accurately assessing the characteristics of a route. Consequently, the model was modified to produce the following descriptors:

1. Total route length
2. Total travel time
3. Total exposure time to the target weapon only
4. Total exposure time to the supporting weapon only
5. Total exposure time to both weapons simultaneously
6. Altitude of terrain at the target
7. Range to the target from the firing position
8. Altitude of the helicopter above the terrain at the firing position
9. Missile time of flight
10. Range to the target at time of missile impact
11. Altitude of the helicopter above the terrain at the time of missile impact
12. Dive angle (climb angle) for running fire
13. Exposure time for the firing event (climb, aiming delay, missile flight, dive)
14. Probability of hitting target

After all model modifications had been made the next major step was execution of the experimental design with the route selection model. This required that the model be used to prepare a route description for each combination of factor levels considered in the experiment. Thus, a total of 72 route descriptions were prepared.

As was done during the Phase II Experiment, route descriptions prepared by the model were collected and then plotted in groups of three to a page. For each subject-situation combination the three running fire alternatives were plotted on one page, and the three hover fire alternatives were plotted on another. Each route sketch was annotated with enough information to determine the direction of travel at all points and the location of the firing position. Each sketch was also identified with an identification number to be used by the subject during the route evaluation exercise. This same number appeared on a data sheet containing all the route descriptor data described earlier.

Now, a new feature of the Trial Two Experiment, a sketch and a statistic sheet, were also prepared for the route that the subject had chosen himself during Phase II. It was reasoned that the same amount of information should be available for all routes being considered by the subject, and of course, the subject's own route was to be used as a reference during the evaluation exercise.

The final step in conducting the experiment was the preparation of a mailer for each subject participating in the experiment. An example of the materials contained in this mailer appears in Appendix F as Exhibit F.2.

Exhibit F.2 is actually a copy of the package received by subject 7. However, some of the materials have been reduced from their original size of 7-1/2x14-1/2. Moreover, the color coding originally used in the route sketches has been lost in the reduction (reproduction) process.

The packages were mailed on 28 February 1972, and as indicated by the cover letter in each package (Exhibit F.2), the subjects were urged to complete the exercise by 8 March 1972. To stress the importance of the material, each package was sent via certified air mail with an air mail return envelope enclosed. Four of the six subjects subsequently met this deadline. However, the remaining two subjects, for various reasons, failed to respond until 24 March 1972. Telephone calls verified that these subjects were late in responding only because of extenuating circumstances. Thus, the response to the Trial Two Experiment was much better than the response obtained in the earlier experiment conducted by mail (see Appendix G).

Analysis and Conclusions

As a first step in the analysis of results, an analysis of variance was performed upon the data obtained during the Trial Two Experiment. This analysis had the objective of determining whether or not the model modifications had had any effect upon the overall acceptability of routes produced by the route selection model. Furthermore, it was desired to determine whether a further indication of population heterogeneity would be obtained from the Trial Two Experiment.

Another objective of the overall analysis was to determine whether the quantitative descriptors prepared for each route alternative had aided the subjects in evaluating the alternatives. In essence it was hoped that these descriptors would permit the subjects to render a more valid judgement of the relative merits of each alternative.

A final objective of the analysis was to test the validity of the procedure proposed in a previous section for predicting the mode of fire that a subject will choose in a given tactical situation.

Analysis of Variance. The reader will recall that the design employed during Trial Two was almost identical to that of the Phase II Experiment. Therefore, the two analyses of variance were similar. The only major difference was that there was no longer an input data set effect to be analyzed from the Trial Two Experiment.

Another point of similarity between the two analyses was the procedure required to account for missing data. As discussed at length in Chapter 4, different factor level combinations did not always produce unique alternatives for the subjects to evaluate during the Phase II Experiment. Thus, the intended complete factorials degenerated into incomplete factorials. The same phenomenon occurred in the Trial Two Experiment.

In the interest of brevity suffice it to state that the methods used to account for missing data in the Phase II analyses were again employed during Trial Two analyses. The effect of this action is that analyses of variance performed upon the data are only approximate, and one must be very careful

in his interpretation of the results. However, the intent of analyses in this section is primarily to compare results between the two experiments. Consequently, it seems reasonable to employ similar methods even if they are only approximate. Nevertheless, if the reader desires to perform an in depth analysis of the type discussed in Chapter 4, data required for the analysis are contained in Tables F.1 through F.3 of Appendix F.

The results of the Trial Two Experiment, as they appear after application of the missing data procedure, are presented in Table F.4. A series of analyses of variance have been performed upon these data, and the significant results are summarized in Figures 21 through 24. Detailed analysis of variance tables corresponding to this summary appear in Appendix F. Also, plots of marginal means are presented in Appendix F to indicate trends corresponding to most of the significant results.

Block Effect

In Figure 21 the reader will note that an analysis of variance has been performed in which data from the Phase II Experiment, corresponding to data collected during the Trial Two Experiment, have been used as though they were a second replication of the Trial Two Experiment. A block effect has been included in the statistical model to differentiate between the two experiments.

It may be noticed that a significant block effect exists for only one subject. Moreover, when subject pairs are analyzed (Figure 23), no significant block effect is present. Thus, it would appear that the two experiments yielded

		Subject					
Source of Variation	Degrees of Freedom	6	7	8	11	12	13
1-Block	1	***					
2-Route	1	***		**	*	**	
3-Perception Model	2			**		***	**
4-Attack Mode	1						
12	1	**		**			**
13	2					**	***
14	1						
23	2						
24	1						
34	2						

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 21.--Summary of Significant Results by Subject

Source of Variation	Degrees of Freedom	Subject 6	7	8	11	12	13
1-Route	1					**	**
2-Perception Model	2						***
3-Attack Mode	1						
12	2						
13	1					*	
23	2						

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 22.--Summary of Significant Results by Subject (Trial Two Only)

Source of Variation	Degrees of Freedom	Subject Pair 7, 11	Subject Pair 8, 12
1-Block	1		
2-Route	1		
3-Subject	1	***	**
4-Perception Model	2		
5-Attack Mode	1		
12	1		***
13	1		
14	2		
15	1		
23	1	**	***
24	2		
25	1		
34	2		***
35	1		
45	2		

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 23.--Summary of Significant Results by Subject Pair

Source of Variation	Degrees of Freedom	Subject Pair 7, 11	Subject Pair 8, 11
1-Route	1		
2-Subject	1	*	***
3-Perception Model	2		
4-Attack Mode	1		
12	1		***
13	2		
14	1		***
23	2		**
24	1		
34	2		

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 24.--Summary of Significant Results by Subject Pair (Trial Two Only)

essentially the same data overall. Consequently, it would appear that the efforts to improve the performance of the route selection model have not been altogether successful. However, it is too early in the analysis to form a definite conclusion to this effect. For example, examination of marginal means in Figure F.17 reveals that for two subjects there is an indication, though not significant, of some improvement. Moreover, subject 6 shows a significantly higher acceptance of model results. For the remaining three subjects the model declined slightly in performance, yet none of the decreases were significant.

As another example, it is seen in Figure 21 that a significantly different route effect was present in the two experiments for three of the subjects. Moreover, a significantly different perception model effect was present for two subjects. Thus, it is possible that the route selection model did yield better results during Trial Two under certain circumstances. In fact, examination of marginal means in Figure F.18 reveals that the results for route one did improve for five of the six subjects during Trial Two. Moreover, Figure F.19 shows that the results achieved using the perception model known as Model One during Trial Two were as good as or better than comparable results achieved during Phase II for every subject. More on this topic of model improvement will appear in a later section of this chapter.

Before concluding the discussion of block effect, it should be noticed from Figures 21 through 24 and the comparable figures in Chapter 4 (Figures 9 through 12), that the incidence of significant results from the Trial Two Experiment is much lower than from the Phase II Experiment. The result is that the Trial Two

Experiment by itself produced very little in the way of statistically meaningful results. Trends can be established from plots of marginal means and compared with comparable trends from Phase II. However, there is significant evidence for only a few of the main effects and interactions included in the statistical model.

At first it was thought that perhaps the statistical model did not fit the data collected during Trial Two. However, Figure 25 shows that the overall fit was as good as or better than that achieved during Phase II. From Chapter 4 the reader will recall that the performance measure P is the ratio of sums of squares of error to total sums of squares and may be viewed as a measure of the degree to which the statistical model fits the data. That is, with little unexplained variability it takes less factor variability to produce a significant result. Yet, while the overall fit was comparable, fewer significant results were obtained from Trial Two. Thus, lack of fit is rejected as a reason for the reduced incidence of significant results during Trial Two. It may be noted, however, that the significant results that were obtained did come primarily from subjects 12 and 13. Such a result is to be expected from Figure 25.

Thus, in the final analysis, one is left to conclude that the incidence of significant results in Trial Two declined for one of two reasons. First, it is possible that the subjects actually were less affected by changes in the factors considered during Trial Two. However, an equally plausible explanation is that reductions in the size of the experiment were primarily responsible for

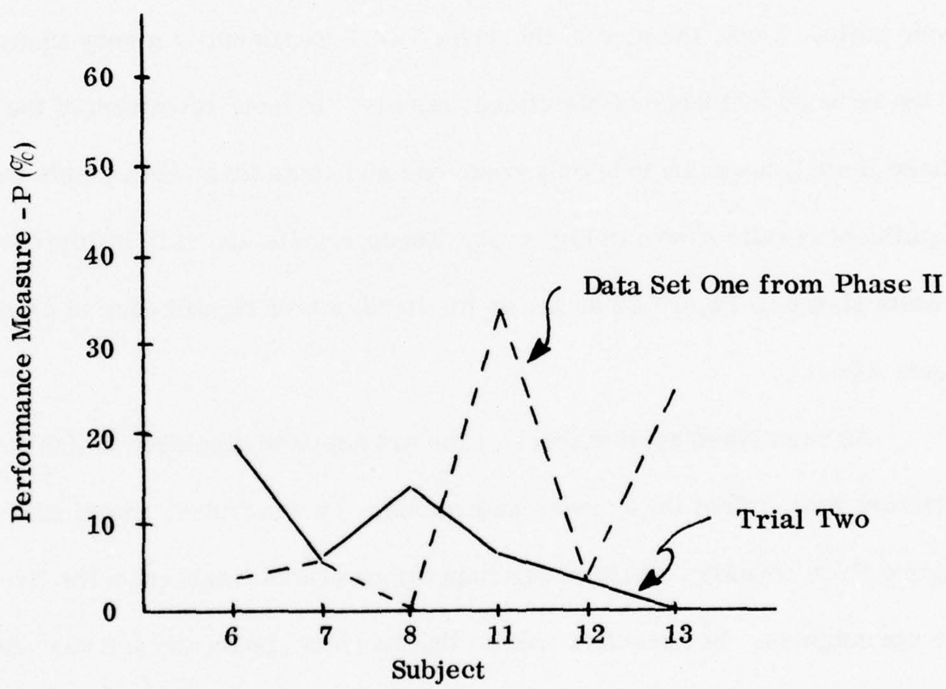


Figure 25.--Plot of Performance Measure by Subject

the decline. During Phase II analyses comparable to those of the Trial Two analyses (see Figures E.7 - E.18 and Figures F.7 - F.12), six degrees of freedom were available in the residual. Only two degrees of freedom were available in the Trial Two analyses. Furthermore, the route factor degrees of freedom declined from three to one. This caused the degrees of freedom associated with interactions involving the route factor also to decline by the same ratio. Thus, the size of the Trial Two Experiment is a very likely cause of the reduced incidence of significant results. In fact, repetition of the Phase II analyses to include only route one and route three data yields the significant results shown in Figure 26. These results are very similar to the results shown in Figure 22 as far as the incidence of significance is concerned.

Route Effect

As mentioned earlier three of the six subjects displayed a significantly different route effect in the two experiments. Furthermore, examination of Figure F.18 reveals that there are indications of this interaction for five of the six subjects. In these five cases, the subjects apparently felt that the route selection model had performed better in constructing route one alternatives during Trial Two than it had during Phase II. On the other hand, in four of the five cases the route three alternatives were judged to be poorer during Trial Two.

The desired result is that there be no route effect or interactions involving the route factor. One would prefer that the route selection model perform equally well in all route selection situations. The analyses reveal

		Subject					
Source of Variance	Degrees of Freedom	6	7	8	11	12	13
1-Route		***		***			
2-Perception Model				**		**	
3-Attack Mode							
12				**			
13							
23							

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure 26.--Summary of Significant Results by Subject (Phase II, Routes 1 and 3 only)

that there may have been some improvement in this direction. First, from Figure 22 it is seen that the route factor significantly interacts with another factor for only one subject. Furthermore, the route effect is significant for only two of the six subjects.

Part of this decline in significance may be due to the reduced size of the Trial Two Experiment as explained previously. However, Figure F.18 reveals that the slope of the marginal mean plot for the route factor has been decreased in magnitude for three of the subjects. Furthermore, it is no longer true that for most subjects the model works better for route 3 than for route 1. In Chapter 4 it was pointed out that the subjects might be correlating their judgment of the performance of the model with their perception of the difficulty of the route selection situation. Such a correlation no longer exists. Therefore, the conclusion is that some progress has been made in reducing the effect that the route selection situation has on model performance. Moreover, the subjects may have given more objective evaluations of model performance during Trial Two. However, still more data are required before final conclusions can be reached in this area.

Attack Mode

Examination of Figures 21 through 24 reveals that the attack mode effect was insignificant in Trial Two. Furthermore, this factor interacted significantly with only one other factor (route) for only one subject. Thus, one might conclude that the improvements made in the hover fire position selection

procedures of the model have achieved the desired result. That is, the model may now represent hover fire and running fire attacks equally well. Such a conclusion is also supported by the marginal mean plots of Figure F.20. However, the lack of significance may be due to the factors cited previously. Moreover, it may still be true that the fire position selection procedures are better in some route selection situations than in others as suggested by the significant route-firing mode interaction for subject 12 and the marginal mean plots of Figure F.22. The attack mode effect will be discussed again in a later section of this chapter.

Perception Model

The perception model effect was one of the most significant effects in the Phase II Experiment. This result was highly desirable since one of the objectives of the experiment was to determine which of the three proposed perception models was most representative of the way in which subjects perceive threat. Unfortunately, it was found that not all subjects perferred the same model. Furthermore, different models performed better in different route selection situations.

In the Trial Two Experiment, only one instance of a significant perception model effect was found as indicated in Figure 22. Moreover, a significant subject-perception model interaction was found for only one of the two subject pairs as indicated in Figure 24. A perception model-route interaction did not exist in the Trial Two Experiment.

Lack of significance in the Trial Two results may be due to the reduced size of the Trial Two Experiment as explained earlier. In the analyses which included a block effect to represent differences between Phase II and Trial Two, significant perception model effects were found for three of the subjects (Figure 21). However, it was also found that for two of these three subjects different perception model effects were present in the two experiments. Thus, it is difficult to draw definite conclusions from a simple analysis of significant results.

A more revealing analysis may be performed by examining the marginal mean plots of Figure F.19. It is seen that with the exception of subject 13, the results of Trial Two are very similar to those obtained during Phase II. For example, there still appears to be a difference between Model One and the other two perception models taken together, although this difference appears to be less for some of the subjects. Furthermore, the Acid Test Model and Model Three continue to be scored closely together in relation to Model One. Of course, missing data still accounts for much of this phenomenon as explained in Chapter 4.

Another point of similarity between results of the two experiments is the effect of the interaction between the route factor and the perception model factor. In the Phase II Experiment a significant interaction was found, but it was shown that the interaction did not affect to any degree the choice of a perception model. In most cases a subject preferring a given model would continue to prefer the same model as the route changed.

In the Trial Two Experiment a very similar effect was found. First, there was not even a significant route-perception model interaction. Furthermore, Figure F.21 shows that a subject preferring a given model almost always continues to prefer the same model in different situations. Finally, a minimax analysis similar to the one conducted in Chapter 4 shows that Model One continues to be the preferred model in the face of uncertainty with respect to the situation in which the model would be applied. Figure 27 shows that should Model One be adopted the worst result would be an average rating of 88%. However, to choose the Acid Test Model could yield an average rating of 65% while a choice of Model Three could yield an average rating as low as 62%.

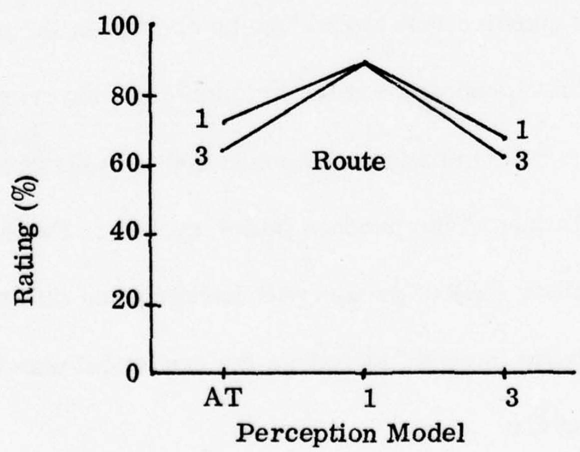


Figure 27.--Perception Model-Route Interaction Across All Subjects (Trial Two)

From the above observations it appears that the Trial Two Experiment yielded essentially the same results as the Phase II Experiment with respect to perception model effect. Thus, the conclusions reached as a result of Phase II are unchanged by the results of Trial Two. Model One is apparently preferred by most subjects in most route selection situations. In the face of uncertainty with respect to the situation in which the model would be applied, one should choose Model One to be used in the route selection model to achieve the highest average rating across all subjects. However, from Figure F.19 it is obvious that Model One is not the model preferred by all subjects. Again, two of the six subjects preferred a model other than Model One. Thus, it would be foolish to choose Model One to the exclusion of all other models. There is a 35% chance that some other model would be the choice of half the entire Army pilot population possessing the backgrounds of the subjects tested. Therefore, at this time it is suggested that Model One be chosen as the most promising candidate of the three proposed perception models. However, it is also suggested that further experimentation be conducted to determine if alterations of the three models tested can produce better results. Furthermore, it is desirable to test other subject groups with backgrounds different from the Phase II subject group in order to reduce the statistical uncertainty of the results achieved so far.

Subject Effect

In Chapter 4 it was shown that the subject factor interacted frequently with other factors in the Phase II Experiment. Furthermore, a strong subject effect occurred in most analyses of variance, although the main effect generally was not as important as the interactions. This conclusion was supported by the data in Figures 16 through 18.

Figures 16 through 18 also showed that subjects 8 and 12 exhibited basically two different modes of behavior. The marginal mean plots of Appendix E indicate that subject 12 behaved in a fashion similar to subject 13. On the other hand, subject 8 was most similar to subjects 6, 7, and 11. Thus, it was concluded that at least two basic modes of decision behavior may have existed within the subject group.

Now, one of the primary objectives of the Trial Two Experiment was to determine whether or not the indication of population heterogeneity achieved during Phase II could be duplicated in a second experiment. The answer is an emphatic yes.

First of all, even though analyses of variance using only Trial Two data yielded very few significant results, it is seen in Figure 24 that a significant subject effect was present in both factorials involving a subject factor. Furthermore, for subject pair (8, 12) the subject factor interacted with all other factors except firing mode.

Next, Figure 28 shows that interactions involving the subject factor comprise a significant portion of the overall variability attributable to interactions. Furthermore, it is seen that the variability attributable to the subject factor for subject pair (8, 12) is larger than the variability attributable to all the other factors combined. It also represents a greater contribution to overall variability than that attributable to the subject factor for subject pair (7, 11). These results are very similar to those obtained in Phase II.

Finally, examination of the marginal mean plots in Figure F.19 reveals that with the exception of subject 13, all subjects exhibited about the same behavior in rating the three threat perception models during Trial Two as they exhibited during Phase II. However, during Trial Two subject 13 changed his ratings significantly. His behavior now appears to be very similar to that exhibited by subjects 6, 7, 8, and 11. The effect of this change is that subject 12 now appears to behave in a fashion unlike any other subject.

Considering the above results, it appears reasonable to conclude that there is a very definite subject effect, and that the subject factor does interact with most other factors. That is, the overall performance of the route selection model is judged differently by different subjects. Moreover, different subjects feel that changes in the route selection situation and the perception model affect the performance of the route selection model in different ways. However, it appears that the population of Army pilots can be divided into two groups, one group containing pilots that generally prefer Model One as a perception

Subjects 7 and 11

Source of Variation	Degrees of Freedom		Sums of Squares		Percent of Total	
Main Effects	5		4215.09		44.9	
Subject		1		1320.17		14.1
Other		4		2894.92		30.8
Interactions	9		2343.75		25.0	
Subject		4		1510.92		16.1
Other		5		832.83		8.9
Residual	9		2816.50		30.1	30.1
TOTAL	23		9375.31		100.0	100.0

Subjects 8 and 12

Source of Variation	Degrees of Freedom		Sums of Squares		Percent of Total	
Main Effects	5		5374.53		51.9	
Subject		1		3243.37		31.3
Other		4		2131.16		20.6
Interactions	9		4149.87		40.1	
Subject		4		2333.67		22.5
Other		5		1816.20		17.6
Residual	9		830.55		8.0	8.0
TOTAL	23		10354.94		100.0	100.0

Figure 28.--Subject Effects and Interactions (Trial Two Data)

model and the other group containing pilots that generally prefer some other model. Yet, as stated previously, more experimentation is required in this area before final conclusions can be drawn. For example, it has been seen that one subject (subject 13) apparently changed his mode of decision behavior between Phase II and Trial Two.

Worth of the Model. As seen in the analyses of variance presented in the preceding paragraphs, ratings given to the route selection model by the subject group vary in very complex ways with almost every factor included in the Trial Two Experiment. This finding is consistent with that of the Phase II Experiment reported in Chapter 4. However, a very important overall question is whether or not the changes made to the route selection model in preparation for the Trial Two Experiment had any effect upon the performance of the model.

In a previous section it was shown that a significant block effect between Phase II and Trial Two existed for only one subject. Thus, there was little indication of an overall improvement in model performance. However, it was also pointed out that the model may have performed much better under certain circumstances.

As an approach to studying this possibility, an analysis similar to one presented in Chapter 4 for the Phase II data has been repeated for the Trial Two data. Figure 29 shows the rating of the route selection model as a function of the perception model used, for two different classes of decision makers

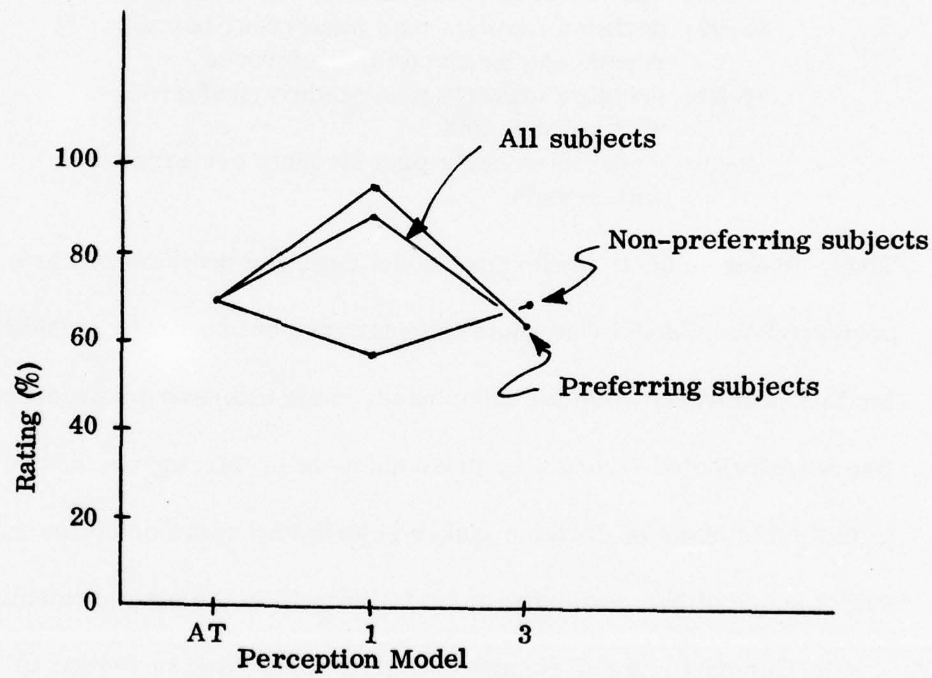


Figure 29. --Overall Model Rating (Trial Two)

(those preferring Model One alternatives over other alternatives, those not preferring Model One alternatives) as well as for all decision makers. The effects of all other factors have been averaged.

The reader will recall that during Phase II and Trial Two the subjects associated the following qualitative statements with the ratings:

100: equivalent to decision maker's route plan,
95-99: decision maker's plan preferred, but no reason can be given for preference,
70-94: decision maker's plan slightly preferred, with reason, and
0-69: decision maker's plan strongly preferred with reason.

Thus, among subjects preferring Model One, the decision maker's plan was preferred over Model One route alternatives, but no reason could be cited for this preference. On the other hand, route alternatives produced by Model One were rejected strongly by those subjects preferring one of the other models. In fact, this class of decision maker rejected all route selection model results with a score either bordering on or falling within the strong rejection region.

Comparing these results with those presented in Figure 19 of Chapter 4 it is seen that an overall improvement in route selection model performance was achieved during Trial Two. Furthermore, while the subjects continued to strongly reject the route alternatives produced by the Acid Test Model and Model Three, the class of subjects preferring Model One was unable to cite any reason for rejecting route plans prepared by Model One. In Phase II these subjects slightly preferred their own plans, with reason. Thus, it is seen once more that if one were forced to construct a route selection model with

only one percieved threat model, Model One would be the best choice. It has achieved a level of acceptability among subjects preferring Model One alternatives over other alternatives that is considered satisfactory. In fact, as discussed in the next section, it may be difficult to ever achieve higher results with any model. However, to choose the one perception model to the exclusion of all others would be a foolhardy venture. A class of decision makers exists that would strongly reject the results produced by this model. In fact, Figure 29 reveals that it may be necessary either to revise the entire route selection model or to develop a new perception model in order to achieve satisfactory acceptance of route alternatives among these subjects.

Quantitative Measures. The reader will recall that the Trial Two subjects were provided a set of quantitative descriptors for each route alternative they were to evaluate. It was hoped that these descriptors would permit the subjects to perform a more objective comparison between their own route plans and those prepared by the model. Unfortunately, it is not obvious that such a result was achieved in Trial Two.

Figures 30 through 34 are scatter diagrams showing the relationships between ratings given the various route alternatives and five quantitative descriptors associated with the alternatives. The data from which these diagrams were prepared appears as Table F.5 in Appendix F. As may be seen, there is no discernible correlation between alternative rating and any of the quantitative descriptors. Furthermore, it is apparent that the subjects were hardly concerned with these factors when they were constructing their own route plans.

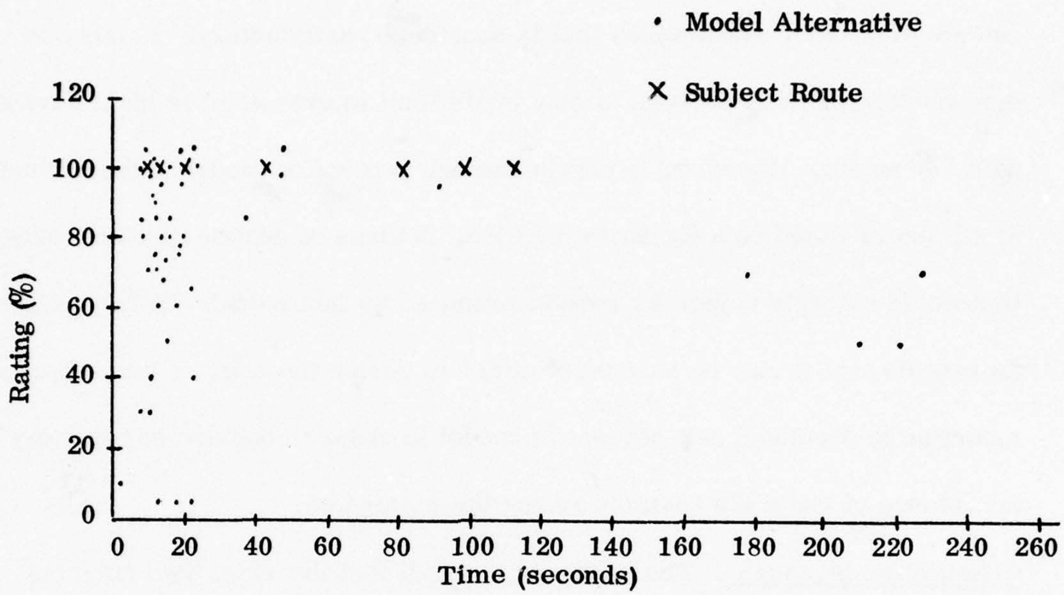


Figure 30.--Rating as a Function of Exposure Time During Attack

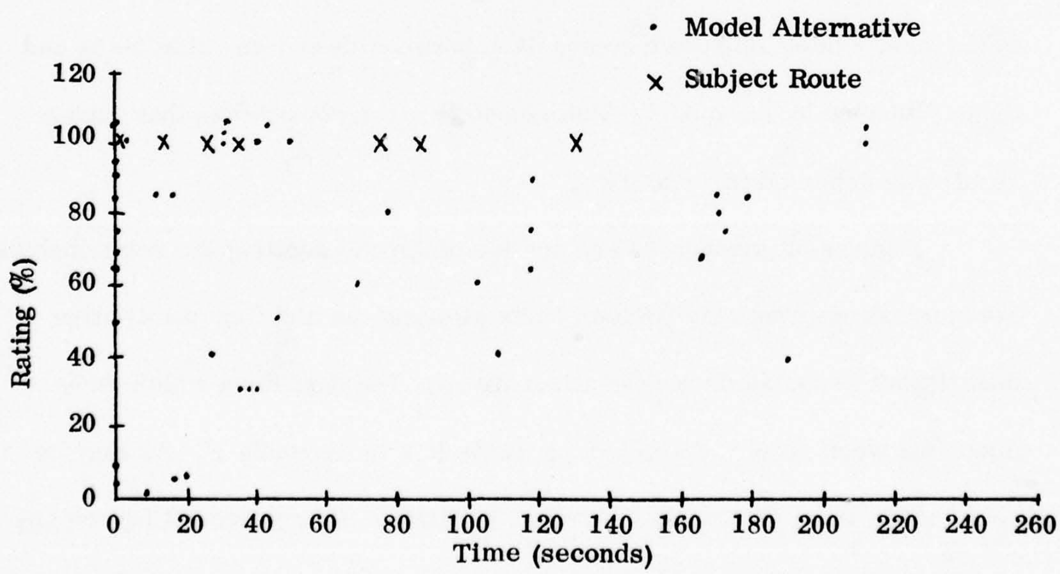


Figure 31.--Rating as a Function of Time Exposed to Target Weapon Only

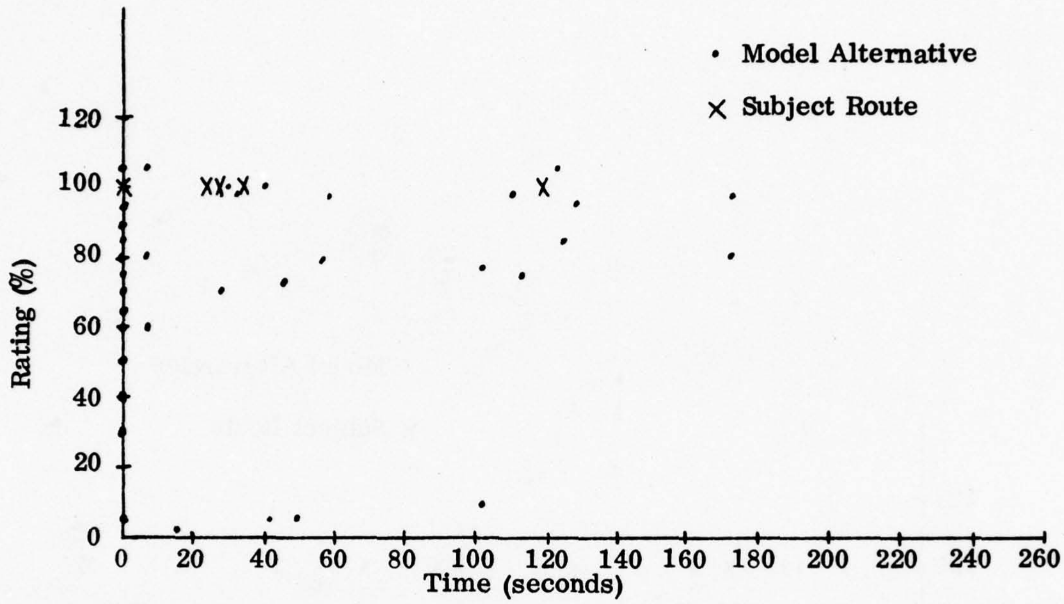


Figure 32. --Rating as a Function of Time Exposed to Supporting Weapon Only

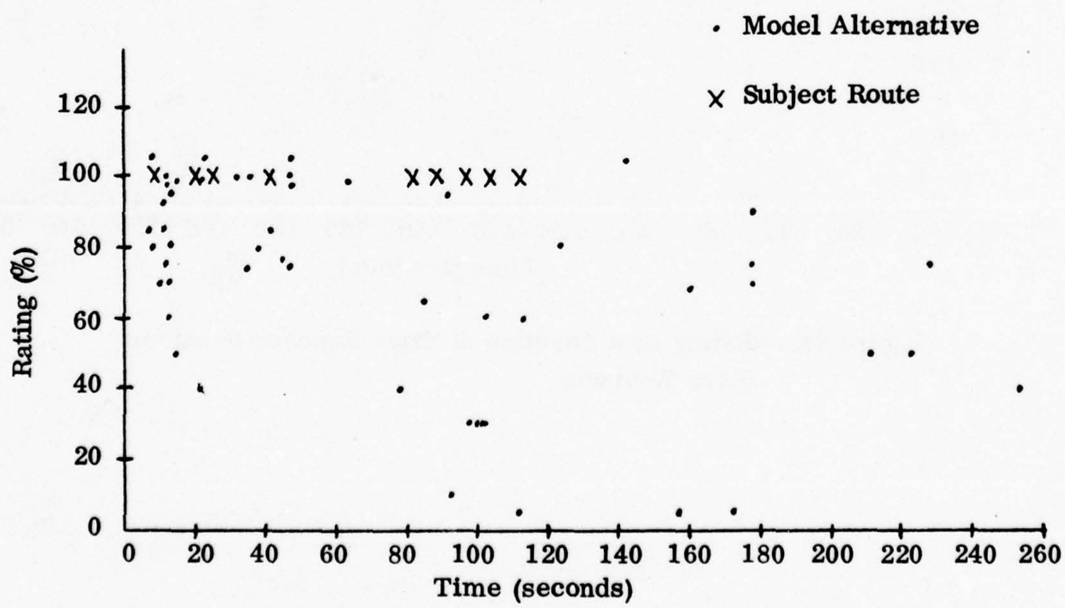


Figure 33. --Rating as a Function of Time Exposed to Both Weapons Simultaneously

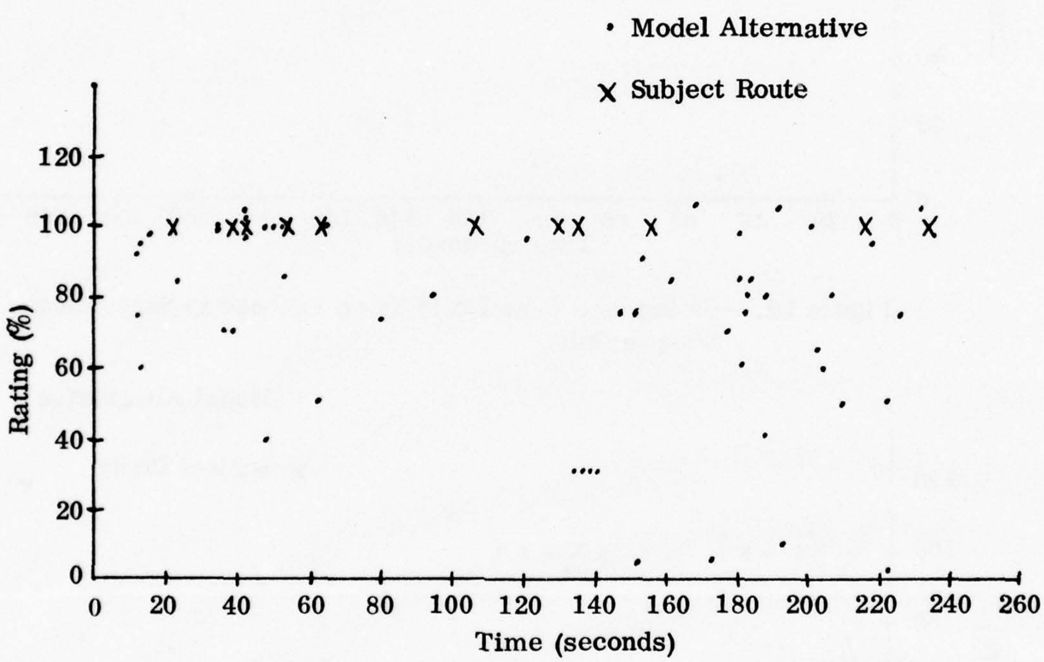


Figure 34. --Rating as a Function of Time Exposed to One or More Weapons

Considering the above results one of two conclusions may be drawn. First, it is possible that none of the five factors considered in Figures 30 through 34 are important to the subjects during route selection. However, this is unlikely since all five factors are related to exposure, and all subjects have indicated minimization of exposure as a principle of choice in route selection.

The other conclusion that might be drawn is that the subjects, in violation of the instructions they were given did not use the factors to assist in rating the route alternatives. Unfortunately, there is no way to determine whether or not this actually was the case. However, it is a likely conclusion.

The net result of the above observations is that it is unknown whether or not the Trial Two subjects experienced difficulty in discerning true physical differences between route alternatives. Furthermore, even if such difficulties did exist, it is unknown whether the quantitative descriptors were helpful in alleviating them. Nevertheless, it would appear from the data in Figures 30 through 34 that the difficulties did exist, but the subjects still failed to use the descriptors.

With such apparently arbitrary results, it is considered very fortunate that the subjects rated the performance of the route selection model as high as they did. In fact, it would appear that any rating of 95 or above (decision maker's route plan preferred, but for no reason) should be about the best overall performance that can be achieved. Thus, the rating received by Model One

from subjects preferring Model One alternatives over other alternatives (see preceding section) is considered satisfactory. Recommendations for future research along these lines will be presented in Chapter 7.

Predicting Mode of Fire. The last analysis required in this chapter is a test of the procedure proposed earlier for predicting the mode of fire that a decision maker will select in a given attack situation. The reader will recall that the procedure is as follows:

> For a particular route selection situation, and using one of the three threat perception models, determine a route that includes a hover fire attack. Denote the overall threat of the route as T_{HF}. Repeat the analysis for a running fire route to obtain T_{RF}. If $T_{HF} < T_{RF}$ then predict that the decision maker will prefer the hover fire result. Otherwise, predict that the decision maker will prefer the running fire route result.

In preparing for the Trial Two Experiment, values of T_{HF} and T_{RF} were determined for every combination of subject, route and threat perception model considered. These data appear in Appendix F at Table F.6. The proposed procedure was then applied to predict the route alternative that each subject would prefer for each combination of situation and perception model. The results of this exercise appear in Table 10 under the heading of Predicted Firing Mode Preference. For example, it is predicted that for route situation one subject six will prefer the hover fire alternative over the running fire alternative if the threat perception model used is the Acid Test Model.

Table 10

Summary of Firing Mode Prediction Procedure Performance

Subject	Route	Firing Mode Actually Selected	Predicted Firing Mode Preference			Actual Firing Mode Preference		
			AT	1	3	AT	1	3
6	1	HF	HF	HF	HF	RF	RF	HF
	3	HF	RF	HF	RF	HF	HF	HF
7	1	HF	RF	HF	RF	HF	RF	RF
	3	HF	HF	HF	HF	HF	-	RF
8	1	RF	RF	RF	RF	HF	-	HF
	3	RF	HF	HF	RF	RF	-	RF
11	1	RF	RF	HF	HF	RF	RF	RF
	3	HF	RF	HF	HF	RF	HF	HF
12	1	HF	RF	RF	RF	HF	-	HF
	3	RF	HF	HF	RF	RF	RF	RF
13	1	HF	HF	RF	RF	-	-	-
	3	HF	HF	HF	RF	-	HF	RF

In examining this class of data in Table 10 it is seen that one of the difficulties discussed at the time the procedure was developed is a common occurrence. That is, different predictions are made depending upon which of the three threat perception models is under consideration. Out of twelve combinations of subject and situation, the three predictions are in agreement only four times. Therefore, it is apparent as suggested earlier that the procedure can be applied with validity only after the threat perception model which applies to a given decision maker has been determined. Of course, at this time such information is not available. All that is known is that most of the subjects apparently preferred the overall route results produced by Model One during Trial Two. Thus, one might use the predicted firing mode preferences prepared for Model One routes in testing the validity of the procedure for those subjects who preferred Model One alternatives. The results of such an approach will be discussed in a paragraph below.

Another class of data appearing in Table 10 is the actual firing mode preference as determined from rating data appearing in Table F.4 of Appendix F. For example, in route situation one, subject six rated the running fire alternative prepared with the Acid Test Model higher than he rated the hover fire alternative. Thus, it is assumed that he preferred the running fire alternative. In those cases where the same rating was given to both alternatives, it is assumed the routes were equally desirable.

In examining this class of data it is seen that there is little indication of a uniform firing mode preference across all three of the threat perception models. That is, in only three cases (excluding ties) out of twelve does a subject pick the same mode of fire from the routes produced by all three of the threat perception models. This may be a further indication that the subjects were not particularly biased against the procedures used to represent either type of attack during Trial Two. However, in comparing the actual firing mode preferences with the predicted firing mode preferences, it is seen that the prediction procedure apparently failed to achieve a very high level of accuracy. For example, if ties are excluded, Acid Test preferences are predicted correctly in only three cases out of ten, Model One preferences are predicted correctly in three cases out of seven, and Model Three preferences are predicted in six cases out of eleven. Even if ties are counted as one-half, the accuracy figures are 4 out of 12, 5-1/2 out of 12, and 6-1/2 out of 12. Finally, if the analysis is restricted to Model One routes and subject 12 is excluded because he did not prefer Model One routes overall, the accuracy figure counting ties is only 7 out of 10. While this is a higher accuracy percentage than others obtained above, it still does not represent a very successful performance.

A final class of data in Table 10 is the firing mode that the subjects actually selected for their own routes during the Phase II Experiment. In comparing these data with the predicted preference data, it is seen that the prediction procedure is no more accurate in predicting subject route firing

modes than it is in predicting firing mode preferences. The procedure is correct only about fifty percent of the time.

The data outlined above are insufficient to classify the prediction procedure as being invalid. As stated previously, the procedure is not intended to predict a firing mode preference nor the actual choice of a firing mode with certainty. Rather, it is recognized that the intrapersonal variation of a decision maker will cause him to give different rankings to route selection model results in repeated trials of the same decision problem. It will also cause him to possibly select different modes of fire to be employed. Trial Two represents only one realization of such a problem. Therefore, it is impossible at this time to say with certainty that the firing mode prediction procedure is or is not valid. While the results outlined above are disappointing they do not form a justification for rejecting the procedure. Instead, further experimentation is required to obtain more statistical evidence.

CHAPTER 6

FORT ORD EXPERIMENT

by Dave Bitters

Introduction

Based upon the results of the experiments conducted at Fort Rucker, an additional experiment was conducted at Fort Ord for the primary purpose of using experienced pilots that were also trained in the mid-intensity combat tactics. A secondary purpose was to alter the procedure to permit more objectivity in comparing model and subject routes.

Procedural Modification

The procedural modification was motivated by the Fort Rucker subject preferences for their own routes even when calculations by the route selection model showed that the subject routes were more exposed. Of course, the previous statement may be very biased toward the route selection models because their exposure measures may be unlike those used by the subjects in actually selecting routes. Nevertheless, the procedure used at Fort Rucker needs to be modified to reduce the bias produced by explicitly using the subject plots as the standard for comparison with the route selection model plots.

The procedural modification was to present all routes for comparison without any specific identification as to which routes were subject routes. The

intent was to deemphasize the subject routes and to disguise the subject route so that they may not even be recognized by the subject.

Subject Qualifications

The United States Army has an ample supply of qualified helicopter pilots that have combat experience; however, most of them have only experienced combat in Southeast Asia. Accordingly, most are only experienced in what would be considered low-intensity combat. The helicopter pilot in Vietnam has not had to cope with anti-aircraft weapons (such as Redeye) on a large scale. It is understood that most helicopter pilots, however well qualified they may otherwise be, are not experienced in the tactics and doctrine of the attack helicopter in the mid-intensity environment. Indeed, such tactics and doctrine had been formulated only a short time before this research was performed in the Basic Attack Helicopter Team (BAHT) experiments (43.5 and 43.6) at Fort Ord, California.

One might argue that the model validation results obtained from the Ohio National Guard and Fort Rucker experiments, as presented in earlier chapters, are of somewhat limited value precisely because the subjects used in those experiments were not trained in the mid-intensity doctrine. For this reason, a sample of opinions from pilots trained in mid-intensity warfare is included in this report. The assumption was that although the pilots so sampled may not have ever faced an antiaircraft weapon as potent as the Redeye, at least they would be intellectually familiar with the problems posed by a significant

antiaircraft threat, and that their behavior (and accordingly their responses to the situations presented to them) would be modified accordingly.

As of early May, 1971, the only unit known to be operationally trained in mid-intensity warfare doctrine was the 155th Helicopter Company (Attack), stationed at Fort Ord, California and attached to the USACDC Experimentation Command (USACDCEC). The 155th had conducted extensive maneuvers against hard-point targets under conditions of a simulated significant antiaircraft threat, in connection with the BAHT experiments mentioned earlier. They were, therefore, familiar with procedures such as knap of the earth flying, running and hover fire, and antiaircraft evasive tactics. They were also well informed of the capabilities and characteristics of the 14.5mm, 23mm and REDEYE antiaircraft weapons. In short, the 155th Helicopter Company was an ideal unit from which to draw subjects for a final comparison experiment.

A two-phase experiment was arranged at Fort Ord, California for May 18, 1972, and June 23, 1972. The experiment involved ten volunteer subjects from the 155th Helicopter Company. Each subject filled out a volunteer information form from which the information appearing in Tables 11 through 14 was obtained. The information in these tables indicates that the subjects were generally highly experienced with their aircraft, were seasoned combat veterans in terms of total combat flight time, and were generally familiar with the problems of mid-intensity combat. Notice in particular that all subjects had been engaged by enemy antiaircraft fire (Table 13), that all but one had engaged hard-point targets (Table 14), and that all but one had received formal instruction in

Table 11
Flight Experience

Subject	Age (Years)	Rank	Service Experience (Months)		Flight Experience (Hours)				
						Combat Zone			
			Total	At Present Duty Station	Total	Total	Gunship	Troop Carrier	Observation
6	32	Cpt.	149	8	2600	1500	1100	400	
7	24	Cpt.	64	21	1750	1300	900	250	150
8	26	CW-2	42	14	1140	700	700		
9	25	1 Lt.	88	20	1250	800	750	20	30
10	30	Cpt.	121	12	4800	1550	1550		
11	26	Cpt.	73	9	2500	1500	800	300	400
12	23	CW-2	36	9	1300	914	914		
13	23	CW-2	37	10	1400	960	950	10	
14	25	CW-2	50	22	1400	660	600	60	
17	28	1 Lt.	111	21	1300	950	945	2.5	2.5
Average	26	—	77	15	1944	1068	921	104	58
Range	23-32	—	36-149	8-22	1140-4800	660-1550	600-1550	0.0-400	0.0-400
Distribution		4 Cpt. 2 1Lt. 4 CW-2							

Table 12

Equipment and Weapon Experience

Subject	Flight Experience (Equipment)			Weapon Firing Experience			
	Gunship	Troop Carrier	Observation	7.62mm	Rocket	Grenades	Missiles
6	UH-1C	UH-1D + H	—	√	√	√	
7	AH-1G	UH-1H	OH-58	√	√	√	
8	UH-1C	—	—	√	√	√	
9	AH-1G	UH-1H	OH-6	√	√	√	
10	UH-1B+C	—	—	√	√	√	
11	UH-1C, AH-1G	UH-1D+H	OH-6A, OH-58	√	√	√	
12	UH-1C	UH-1D	—	√	√	√	
13	UH-1C	UH-1D	—	√	√	√	
14	UH-1C	UH-1H	—	√	√	√	
17	UH-1C	UH-1D	LOH	√	√	√	

Table 13

Air Defense Experience
(Heaviest Weapon Encountered)

Subject	30 Cal	50 Cal	37mm	57mm	Were you engaged?	Did you engage?
6			√		Yes	No
7			√		Yes	Yes
8		√	√		Yes	Yes
9			√		Yes	No
10			√		Yes	No
11		√	√		Yes	Yes
12			23mm		Yes	Yes
13			√		Yes	No
14		Quad .51 cal	√		Yes	Yes
17			√		Yes	Yes

Table 14
Heavy Target Experience

Subject	Experience	Weapon Used	Mid-Intensity Warfare Training
6	Yes	Rockets, 22mm	Yes
7	Yes	HEAT rounds	Yes
8	Yes	2.75 HEAT, rocket	Yes
9	Yes	2.75 HEAT, rocket	Yes
10	Yes	Rockets, 22mm	Yes
11	Yes	2.75 in. FFAR	Yes
12	Yes	2.75 FFAR (10 & 17 lb.)	Yes
13	Yes	17 lb. 2.75 FFAR	Yes
14	No	—	Yes
17	Yes	2.75 HEAT	No

Table 15
Fort Ord Experimental Design

Subject	Map Board	Route 1						Route 2					
		Target	Co-ordinates		Additional Threat	Co-ordinates		Target	Co-ordinates		Additional Threat	Co-ordinates	
			X	Y		X	Y		X	Y		X	Y
6	A	14.5mm	2630	1010	23mm	3600	1220	23mm	3600	1220	14.5mm	2630	1010
7	B	14.5mm	8070	2300	23mm	8640	2500	23mm	8640	2500	14.5mm	8070	2300
8	C	14.5mm	8070	2300	23mm	8770	4440	23mm	8770	4440	14.5mm	8070	2300
9	B	14.5mm	8070	2300	23mm	8640	2500	23mm	8640	2500	14.5mm	8070	2300
10	C	14.5mm	8070	2300	23mm	8770	4440	23mm	8770	4440	14.5mm	8070	2300
11	D	23mm	8640	2000	REDEYE	8770	4440	REDEYE	8770	4440	23mm	8640	2000
12	A'	14.5mm	2630	1010	23mm	3600	1220	23mm	3600	1220	14.5mm	2360	1010
13	B'	14.5mm	8070	2300	23mm	8640	2500	23mm	8640	2500	14.5mm	8070	2300
14	C'	14.5mm	8070	2300	23mm	8770	4440	23mm	8770	4440	14.5mm	8070	2300
17	D'	23mm	8640	2000	REDEYE	8770	4440	REDEYE	8770	4440	23mm	8640	2000

mid-intensity warfare tactics. Judging from the extensive flight experience and the number of months at Fort Ord (Table 11) of the subject who did not claim formal mid-intensity training, it seems reasonable to assume that he was thoroughly familiar with the doctrine through on-the-job training. In short, the subjects interviewed appeared to be ideally qualified to assist in the validation of the DYNFLITE route selection model. Moreover, their cheerful cooperation made working with them a pleasure.

Phase I Experimentation

The experimentation session conducted on May 18, 1972, followed the procedure outlined in Chapter 3 with one exception, to be discussed below. Otherwise, any deviation in the experimental procedure, with whatever bias might have resulted therefrom, is totally due to the fact that the experiments at Fort Rucker and Fort Ord were conducted by different individuals. Every effort was made to guarantee that the format of Chapter 3 was carefully followed.

The only planned deviation from the format of the Fort Rucker experiment dealt with the map boards given to four of the subjects. The reader may recall that the second part of the Phase I experiment was a map board exercise in which each subject was given one of four map boards. Each map board consisted of a computerized representation of a contour map of the battlefield. Each map had a designated starting point, and two sites indicated as locations of enemy weapons. Each subject was given two overlays: one showing forestation and the other indicating regions of intervisibility with respect to each of the two weapon sites. Thus the subjects were given more information than they

might have in an actual tactical situation. In an actual situation a pilot probably would not have intervisibility information at hand. He would have the benefit of contour maps and aerial photographs showing forested areas, however. Thus it was natural to wonder if the absence of line-of-sight information would significantly alter the preference routings made by the subjects during the Phase II experiment. Accordingly, four subjects were denied access to the intervisibility overlays. The subjects were instructed to draw two routes, one to each target, on plastic overlays provided to them (see Chapter 4). The routes were supposed to reflect the flight plans that the subject would select were he actually confronted with the situations represented. Each subject had access to three computer-generated isometric plots of the battlefield showing the forested areas in green.

The subjects were thoroughly briefed on the type of aircraft to be used for the hypothetical attack, as well as on the type of armament they would have. They were given range and lethality characteristics of the three types of weapons that they might encounter. They were also given kill probability data for their own weapons. Examples of the instructions given to the subjects can be found in Appendix B.

The design format used in the map board experiment is shown in Table 15, which lists the subjects by number and indicates which map board each was given. The "prime" notation after the map boards of subjects 12, 13, 14, and 17 indicates that those particular map boards did not have the intervisibility overlays affixed. The rows of Table 15 are to be interpreted as follows: Subject 6* used

---

*Subject numbers started with 6 to facilitate comparison with the experiment at Fort Rucker.

map board A, which required that his first route be drawn to attack the 14.5mm weapon at map co-ordinates X = 2630, Y = 1010. A second weapon (23mm) at co-ordinates X = 3600, Y = 1220 posed a potential threat when in range and intervisible with the pilot. For the second route the pilot was required to attack the 23mm with the 14.5mm weapon posing the additional threat. The other lines of Table 15 are to be interpreted similarly.

Each subject was asked to specify whether his designated mode of attack was to be running fire or hover. The results are shown in Table 16.

Table 16

Subject Fire Mode Choices

Subject	Route 1	Route 2
6	RF	HF
7	RF	RF
8	HF	HF
9	HF	HF
10	HF	HF
11	HF	HF
12	HF	HF
13	RF	HF
14	HF	HF

Judging from the written comments, one would conclude that the choice of mode of fire was based largely on the tactical situation (e.g., utilization of existing cover) rather than on any uniformly applied doctrine or on convenience to the pilot. The reader should therefore be cautioned against using the results of Table 16 as a basis for a regorous statistical inference regarding the relative merits of running fire and hover fire.

Phase II Experimentation

The first part of the Phase I experiment was designed to elicit sufficient information from the subject to permit the construction of his perceived threat function (see Chapter 3). The perceived threat function in turn is an integral part of the Acid Test decision model which was discussed in Chapter 3. The reader will recall that decision models one and three and the Acid Test Model present three rather divergent views of the manner in which a pilot might approach a target, based upon the way he subjectively assesses the threat. Models one and three make some rather bold assumptions about the way a pilot would react in threatening and non-threatening situations. The Acid Test Model on the other hand is more personalistic in the sense that it does not presuppose a given behavioral pattern but rather infers a behavioral pattern from the subject's responses. The Acid Test Model in that sense serves as a counterpoint to the other models, a control, so to speak.

The data obtained from the first part of the Phase I experiment were encoded and incorporated in programs RTSELH and RTVAL. Program RTSELH generates a route from the starting point to the target and back to the starting point, based on the decision rule employed. That is, RTSELH selects that path from the starting point to the target such that perceived threat is minimized. The output of RTSELH becomes the input to RTVAL, which evaluates the "tactical difficulty" of each route relative to the decision rule used, and which generates plotter instructions permitting each route to be traced on a vellum overlay.

As one changes the decision model, one obtains different definitions of perceived threat, and hence one is likely to obtain different routes for the same situation. Indeed, the purpose of the Phase II experiment was to obtain an a posteriori comparative evaluation by the subjects of the routes generated by the various decision rules.

The total number of plots generated by RTSELH/RTVAL for each subject was twelve. Each subject was given plots of route 1 - running fire, route 2 - running fire, route 1 - hover fire, and route 2 - hover fire for decision model 1, decision model 3, and the Acid Test Model. The starting co-ordinates and target locations in each case corresponded to those which the subjects used during the map board exercise of the Phase I experiment. Thus each subject was given model 1, model 3, and Acid Test routes in both running and hover fire attack modes, for each of the two situations (routes 1 and 2) encountered in the Phase I experiment.

It was observed earlier that the Acid Test routes could be viewed as controls for the purpose of multiple comparison, because they presumably represent the subjects' true feelings about perceived threat. However, better controls do exist; namely, the routes which the subjects drew during the Phase I map board exercise. It is assumed that those routes represent the a priori (or unquantified) optimum routes; that is, it is assumed that those routes would actually be used by the subjects in the absence of evidence other than that which was provided to them during the Phase I experiment. Thus the subject-generated routes could be used as a basis for comparison as was done in the Fort Rucker experiment.

However, an unforeseen bias occurred in the Fort Rucker experiment as a result of the fact that the subjects could identify their own routes and were required to use them as comparison standards. Basically the difficulty was that the subject routes were used simultaneously as comparison standards and as routes to be ranked against the RTSELH/RTUAL routes. It turned out that the dual roles of the subject routes were incompatible: the subjects tended to systematically prefer their own routes to those of the three decision models. It was believed that the subject-generated routes would not necessarily be uniformly preferred if their identity could be somehow concealed. Accordingly, the subject-routes of the map board exercise were encoded and run through program PVAL. Program PVAL produced, as output, instructions to the plotter which allowed the subject-routes to be plotted on vellum in identically the same foremat as those of RTSELH/RTUAL. Thus it was possible to externally mask the identity of the subject routes.

The rules of the Phase II experiment were altered slightly from those of the Fort Rucker experiment to accommodate the absence of a prespecified standard. Each subject was given four groups of plots designated route 1 - running fire, route 2 - running fire, route 1 - hover fire, and route 2 - hover fire. Each group contained at least three but not more than four plots. Those groups containing four plots corresponded to the route and choice of firing mode made by the subject during the map board exercise of Phase I. Thus, for example, if a subject chose hover fire for route 1 and running fire for route 2 in drawing his plots, those groups designated route 1 - hover fire and route 2 - running fire

would contain only three plots--Model 1, Model 3, and Acid Test. The plots were arranged randomly within each group.

Thus, in all but two cases the subjects received a total of fourteen plots. Subjects 10 and 14 received only twelve plots. Regrettably an anomaly in the starting co-ordinates given to subjects 10 and 14 in the map board exercise resulted in routes which were believed to be significantly different than those which would have resulted had the starting co-ordinates been the same as those input to RTSELH. The error unfortunately was not discovered until it was too late for a correction. The absence of the subject-plots for subjects 10 and 14 constitutes a potential bias as will be described later in this chapter. The resulting bias may tend to make certain evidence of questionable value. A full treatment of the problem will be given in the section on the analysis of results. Regardless, it was deemed expedient to omit the subject-plots for subjects 10 and 14 and proceed with the experiment as originally planned.

The subjects were instructed to make a multiple rank comparison within each group. That is, the plots were to be ranked by the subjects, first qualitatively, then quantitatively. The route deemed best by the subject was to be given a value of 100, with the other routes being given lesser numerical scores according to the scheme outlined in Chapter 4. Tie scores were permitted in the cases where the subject was indifferent between two routes. (Note, in this context, that in some cases Models 1 and 3 generated identical routes. Indifference is axiomatic in such situations.) A typical ranking for the two route-1 groups is shown in Table 17. The symbols in the table are Rt 1 for Route 1,

RF for Running Fire, HF for Hover Fire, S for Subject Plot, AT for Acid Test Model, M1 for Model One, and M3 for Model Three

The subjects were then instructed to rank all route-1 plots together with all route-2 plots according to the rules described above. Thus in essence the categories route 1 - running fire and route 1 - hover fire were combined, and the combined category was ranked; the route 2 combined category was ranked in the same manner. Thus, a typical aggregated ranking is shown in Table 18.

Table 17
Typical Grouped Route Ranking

Plot	Value
Rt 1 - RF - S	100
Rt 1 - RF - AT	90
Rt 1 - RF - M2	85
Rt 1 - RF - M1	50
Rt 1 - HF - AT	100
Rt 1 - HF - M3	98
Rt 1 - HF - M1	25

Table 18
Typical Aggregated Route Ranking

Plot	Value
Rt 1 - HF - AT	100
Rt 1 - RF - S	99
Rt 1 - HF - M3	95
Rt 1 - RF - AT	80
Rt 1 - RF - M3	75
Rt 1 - HF - M1	25
Rt 1 - RF - M1	1

For the purpose of the analysis the grouped rankings were ignored. The main reason for making the subjects do the grouped rankings was to familiarize them with the plots. A secondary reason was to familiarize them with the ranking scheme.

The rules for the Phase II experiment were essentially the same as those for the map board experiment. (Of course in the Phase II experiment the subjects had to evaluate routes rather than construct them.) All subjects had access to

the three computer drawn isometric maps of the battlefield. Subjects 6-11 had the line-of-sight overlays while subjects 12, 13, 14 and 17 did not. Each subject was given a copy of the descriptive material which accompanied the map board in the Phase I experiment. Use of the material was for the purpose of refamiliarizing the subject with the nature of the problem (recall that Phases I and II were conducted more than a month apart). The entire Phase II experiment was conducted in about one hour.

During the course of the ranking exercise, references to the decision models were deliberately kept as obscure as possible. The subjects were told only that the routes were derived from the information supplied during Phase I. Naturally, some of the subjects wondered if reproductions of their routes drawn during the map board exercise were among the plots given them. The response to their query was merely that their routes had been used in the analysis. It is unlikely that many of the subjects were fooled, especially in view of the fact that some of the groups given them contained four plots and others contained three. Thus the danger of biased results was not completely overcome. The subjects were urged however to do nothing more than compare the plots given to them, without regard to the map board exercise of the previous experiment. There is no reason to believe that the subjects did not make a sincere effort to comply with the instructions.

When the ranking exercise was completed, the subjects were instructed to identify the routes which they believed most closely resembled the ones they had constructed during the map board exercise of Phase I.

Analysis of the Results

The first question to be answered is whether or not the masking of the subject plots was successful. One can be absolutely certain that the rankings of the plots are unbiased (in the sense that they are influenced by the prior preference of the subject-generated plots) only if the subjects are not able to easily distinguish their own routes from among the others. The above question can be admirably addressed by a straightforward inferential technique. Eight of the ten subjects were given packets containing fourteen plots, two of which were computerized representations of the routes they had themselves constructed a month earlier. (Recall that a programming anomaly rendered the subject plots for subjects 10 and 14 useless.) The subjects were instructed to select from among the fourteen plots the two which they believed most closely represented their own routes. Recall that the fourteen plots were divided into four groups, two of which contained four plots each. Clearly the subjects would not even consider the other groups; prior information told them those groups contained no subject-plots. Thus the subjects were to select one plot from each of two groups of four given to them. There are $\binom{4}{1} \times \binom{4}{1} = 16$ distinguishable pairs of plots which can be selected in this fashion. The number of pairs which contain no subject plot is $\binom{3}{1} \times \binom{3}{1} = 9$. Thus the number of pairs which contain at least one correctly identified plot is $16 - 9 = 7$. Hence if a subject were merely guessing which two plots were representations of his own routes, the probability of his making at least one correct selection would be $\frac{7}{16}$. With eight subjects making selections of plots, the hypothesis that the subjects cannot necessarily

identify their own routes and therefore make random selections would imply the following: the probabilities that exactly u of the subjects correctly identify at least one plot is given by the binomial distribution. That is,

$$P(u) = \binom{8}{u}\left(\frac{7}{16}\right)^{u}\left(\frac{9}{16}\right)^{8-u} \qquad u = 0, 1, 2, \ldots 8 \ ,$$

where there are eight subjects.

Only one subject failed to identify at least one of his own plots. The probability that seven or more subjects make a correct identification is

$$P(7) + P(8) = 8\left(\frac{7}{16}\right)^{7}\left(\frac{9}{16}\right) + \left(\frac{7}{16}\right)^{8} \cong .0151.$$

More significantly, only two subjects failed to identify both plots correctly. The probability of this event is

$$\binom{8}{6}\left(\frac{1}{16}\right)^{6}\left(\frac{15}{16}\right)^{2} + \binom{8}{7}\left(\frac{1}{16}\right)^{7}\left(\frac{15}{16}\right) + \binom{8}{8}\left(\frac{1}{16}\right)^{8} =$$

$$= 28\left(\frac{15^{2}}{16^{8}}\right) + 8\left(\frac{15}{16^{8}}\right) + \left(\frac{1}{16^{8}}\right) \cong 1.495 \times 10^{-6}$$

Thus the evidence overwhelmingly suggests that the subjects were not guessing; that is, after more than a month they were generally able to identify correctly the plots which depicted their own routes. The effort to mask the subject-plots in order to eliminate the bias discussed earlier was therefore clearly a failure. Thus the question of bias in favor of the subject-plots remains open throughout the present discussion.

There are two possible reasons for the failure of the masking attempt. First, of course, it is possible that randomly selected subjects would generally be able to identify their own plots under any circumstances. It would thus be futile to attempt to design an experiment which would eliminate subject bias. Second, it is possible that the subjects were able to deduce at the beginning of the Phase II experiment that two of the routes were their own. Aside from the fact that such a strategy appears to be an obvious one to use, two major clues could have aided the subjects in their deduction: 1) two of the subjects had only twelve plots; 2) those subjects who received fourteen plots got two groups of three plots and two groups of four plots. The lack of uniformity both in the number of plots given to the subjects and in the number of plots within each group appear in retrospect to provide rather obvious clues. Of course the subjects were still required to make the appropriate selections, but the possible presence of prior clues as to the intent of the experimenter might have made their task much easier. It is indeed unfortunate if the efforts to mask the identity of the subject plots were negated by the lack of uniformity described above. About the only alternative would be to produce some bogus plots so that each subject would receive four groups of four each.

Regardless of the potential bias described above, there is no reason to believe that the subjects made less than an honest attempt to evaluate the relative merits of the plots presented to them, according to the instructions and in the spirit of the experiment. Thus, although the significance of the results may be somewhat suspect, they should not be dismissed as altogether meaningless.

Because the subject-plots were not identified as standards for comparison, the analysis approach used in the Fort Rucker experiment was not applicable to the Fort Ord data. Thus it is necessary to explain briefly how the results were compiled and what, if any, significance they possess.

Two separate analyses were in fact performed. It was believed that they would produce somewhat different results and thus would provide a basis for comparison by the decision maker. Although the data compilation technique was similar in each case, it will be helpful to describe each separately.

Unweighted Analysis. Table 19 presents typical responses provided by the subjects and, as such, will provide the basis of a tutorial illustration of the manner in which the unweighted rankings were obtained.

Table 19

Typical Subjects' Responses

Plot	Subject A Values	Subject B Values
Rt 2-HF-S	100	75
Rt 2-HF-AT	99	0
Rt 2-HF-M1	25	10
Rt 2-HF-M3	25	100

Without regard to the numerical values given by the subjects, we can obtain the rankings shown in Table 20.

Table 20

Subject Rankings

Subject A	Subject B
Rt 2-HF-S Rt 2-HF-AT Rt 2-HF-M1, Rt 2-HF-M3	Rt 2-HF-M3 Rt 2-HF-S Rt 2-HF-M1 Rt 2-HF-AT

Thus, preference is indicated by relative vertical position: subject A prefers plot S to plot AT, plot AT to plots M1 and M3, and declares M1 and M3 to be tied, for instance. It is evident from Table 20 that subjects A and B by no means agree on the ranking. Therefore, the rankings must be combined in some sort of consistent fashion. The approach which was taken was to determine what amounts to an average ranking. Thus the rankings in Table 20 need to be encoded in a consistent numerical format. To do this one can develop a transitive* ranking function which can be represented in matrix format:

Subject A

$$\begin{array}{c} \\ S \\ AT \\ M1 \\ M3 \end{array} \begin{array}{c} \begin{array}{cccc} S & AT & M1 & M3 \end{array} \\ \begin{pmatrix} 0 & 1 & 2 & 2 \\ -1 & 0 & 1 & 1 \\ -2 & -1 & 0 & 0 \\ -2 & -1 & 0 & 0 \end{pmatrix} \end{array}$$

*The transitive property implies that if X is preferred to Y and Y is preferred to Z, then X is preferred to Z.

The interpretation of the matrix entries is the following: M(P, Q)=K means that plot P is preferred to plot Q by K units. There are three cases. First, as in the case of M(AT,S) = -1 the quantity is negative. This means that in fact S is preferred to AT by one unit. (Note that in fact M(S,AT) = 1). Second, as illustrated by M(M1,M3) = 0, if the quantity is zero, then M1 and M3 are tied in the preference ranking. The third use of course is where M(P,Q) > 0, as illustrated by M(S,M3) = 2. Thus, for example, S is preferred to M3 by two units. One can make a similar representation of subject B's rankings.

Subject B

$$
\begin{array}{c}
 \\ S \\ AT \\ M1 \\ M3
\end{array}
\begin{array}{c}
\begin{array}{cccc} S & AT & M1 & M3 \end{array} \\
\begin{pmatrix}
0 & 2 & 1 & -1 \\
-1 & 0 & -1 & -3 \\
-1 & 1 & 0 & -2 \\
1 & 3 & 2 & 0
\end{pmatrix}
\end{array}
$$

Two important facts should be noted: 1) for a given transitive ranking matrix, any row will produce the same rank ordering (this is because it is always true that M(P,Q) = -M(Q, P)); 2) in order to recover the original ranking from a transitive ranking matrix it is sufficient to know the algebraic sign of each entry (thus, for instance P is preferred to Q if and only if M(P,Q)>0).

To obtain the composite (or average) ranking, one simply adds the two matrices componentwise (or averages the components). It is then possible to obtain the composite ranking:

Subject (A, B)

$$
\begin{array}{c}
\\ S \\ AT \\ M1 \\ M2
\end{array}
\begin{array}{c}
\begin{array}{cccc} S & AT & M1 & M2 \end{array} \\
\begin{pmatrix}
0 & 3 & 3 & 1 \\
-3 & 0 & 0 & -2 \\
-3 & 0 & 0 & -2 \\
-1 & 2 & 2 & 0
\end{pmatrix}
\end{array}
$$

One can thus recover the composite ranking as shown in Table 21 for our example.

Table 21
Illustrative Composite Ranking

Subject (A, B) Ranking	
Rt 2-HF-S	(because M(S,AT), M(S,M1), M(S,M3) > 0)
Rt 2-HF-M3	(because M(M3,AT), M(M2,M1) > 0)
Rt 2-HF-AT, Rt 2-HF-M1	(because M(AT,M1) = 0)

Weighted Analysis. The analysis utilizing the actual numerical values provided by the subjects required an initial value judgment by the analyst. Consider, for example, the response of hypothetical subject B (Table 19). Recall that the weighted ranking was:

Rt 2-HF-M3	-	100
Rt 2-HF-S	-	75
Rt 2-HF-M1	-	10
Rt 2-HF-HT	-	0

Thus subject B preferred plot M3 to all others. Presumably the degree of preference is indicated by the accompanying numbers. The numbers could easily be transformed into percentages. Thus one might interpret the above results to mean that plot S is 75% as good as plot M3. The problem which arises is in comparing plots M1 and AT, for instance, or plots S and M1. Suppose that plot M3 were eliminated from the comparison. Would the subject simply add 25 to the other three numbers to obtain the ranking:

Rt 2 - HF-S	-	100
Rt 2-HF-M1	-	35
Rt 2-HF-AT	-	25

or would he employ the scaling factor $\frac{100}{75}$? In the latter case the ranking would be:

Rt 2-HF-S	-	100
RT 2-HF-M1	-	$13\frac{1}{3}$
Rt 3-HF-AT	-	0

Again, if plot S were removed one could obtain either of the following rankings (by adding 90 in the first case or multiplying by 10 in the second):

Rt 2-HF-M1	-	100	Rt 2-HF-M1	-	100
Rt 2-HF-HT	-	90	Rt 2-HF-AT	-	0

Of course the responses which the subject would actually give under the modified situations described above can only be conjectured. However, the presence of

a response of zero for plot AT indicates total rejection; one might reasonably assume from the nature of the response that the subject would award AT a score of zero regardless of the scores assigned to any of the other routes. That is, in a pairwise comparison of AT with any other route, in which the other route were mandatorily scored 100, AT would be given a score of zero. The scaling factor method of comparison is consistent with this assumption.

One can define a ranking function M(P,Q) as follows: Suppose the number associated with plot P (subject's response) is a; suppose also that the subject assigns number b to plot Q. Then define $M(P,Q) = \frac{a}{b}$. Note that P is preferred to Q if and only if $M(P,Q) > 1$. From a technical point of view the reader may wonder what the significance of $M(P,Q) = \frac{a}{b}$ is in the case where $b = 0$. Of course theoretically there should be no objection to having $M(P,Q) = \infty$. That would simply mean that Q is never preferred (the case $\frac{0}{0}$ was not encountered so it need not be considered). In view of the practical limits of the computer, however, it was deemed expedient to replace a response of 0 by .001 wherever encountered. If interpreted carefully the analysis will yield the same conclusions regardless. For the hypothetical example of Table 19 the resulting weighted matrices are:

Subject A

$$
\begin{array}{c|cccc}
 & S & AT & M1 & M3 \\
\hline
S & 1 & \frac{100}{99} & \frac{100}{25} & \frac{100}{25} \\
AT & \frac{99}{100} & 1 & \frac{99}{25} & \frac{99}{25} \\
M1 & \frac{25}{100} & \frac{25}{99} & 1 & 1 \\
M3 & \frac{25}{100} & \frac{25}{99} & 1 & 1
\end{array}
$$

Subject B

$$
\begin{array}{c|cccc}
 & S & AT & M1 & M3 \\
\hline
S & 1 & \frac{75}{.001} & \frac{75}{10} & \frac{75}{100} \\
AT & \frac{.001}{75} & 1 & \frac{.001}{10} & \frac{.001}{100} \\
M1 & \frac{10}{75} & \frac{10}{.001} & 1 & \frac{10}{100} \\
M3 & \frac{100}{75} & \frac{100}{.001} & \frac{100}{10} & 1
\end{array}
$$

The combined ranking is obtained in this case by multiplying the entries of the matrices together component by component. Thus if $M_A(P,Q)$ and $M_B(P,Q)$

represent the ranking function values for subjects A and B, the corresponding value of the combined ranking function is $M_{(A,B)}(P,Q) = M_A(P,Q)M_B(P,Q)$. Accordingly the composite ranking function for the above example is

Subject (A, B)

$$
\begin{array}{cc}
 & \begin{array}{cccc} \mathrm{S} & \mathrm{AT} & \mathrm{M1} & \mathrm{M3} \end{array} \\
\begin{array}{c} \mathrm{S} \\ \mathrm{AT} \\ \mathrm{M1} \\ \mathrm{M2} \end{array} &
\begin{pmatrix}
1 & 7.6 \times 10^{4} & 30 & 3 \\
1.3 \times 10^{-5} & 1 & 4.0 \times 10^{-4} & 4.0 \times 10^{-5} \\
3.3 \times 10^{-2} & 2.5 \times 10^{3} & 1 & 10^{-1} \\
3.3 \times 10^{-1} & 2.5 \times 10^{4} & 10 & 1
\end{pmatrix}
\end{array}
$$

which yields

$$
\begin{array}{cc}
 & \begin{array}{cccc} \mathrm{S} & \mathrm{AT} & \mathrm{M1} & \mathrm{M3} \end{array} \\
\begin{array}{c} \mathrm{S} \\ \mathrm{AT} \\ \mathrm{M1} \\ \mathrm{M2} \end{array} &
\begin{pmatrix}
1 & \infty & 30 & 3 \\
0 & 1 & 0 & 0 \\
3.3 \times 10^{-2} & \infty & 1 & 10^{-1} \\
3.3 \times 10^{-1} & \infty & 10 & 1
\end{pmatrix}
\end{array}
$$

upon replacing .001 by zero in the subject B matrix. One can then recover the ranking by invoking the rule that P is preferred to Q if and only if $M(P,Q) > 1$. Thus one obtains the ranking

Table 22

Illustrative Ranking from Weighted Analysis

Subject (A,B)
Rt 2 - HF - S
Rt 2 - HF - M3
Rt 2 - HF - M1
Rt 2 - HF - AT

The reader is invited to compare Tables 21 and 22.

Factors Analyzed

The experimental design was utilized to develop a variety of rank orderings to consider a variety of situations. Recall (Table 15) that four different route selections were made by each subject, and four of the subjects were denied line of sight information.

The first ranking which was developed could be termed the overall ranking. In the overall ranking, all subject rankings except those of subjects 10 and 14 were combined according to the procedure outlined above. Other rankings were made to compare various effects:

1) Route. The route 1 rankings of subjects 6, 7, 8, 9, 11, 12, 13, and 17 were combined and compared with the route 2 rankings of the same subjects to see if the factor of the particular route involved made any difference. It should be noted that one would not a priori suspect a significant difference because

abstractly one route should not pose more difficulties than any other (that is, one would expect the results to be the same even if all of the routes numbered 1 were renumbered 2 and vice versa).

2) Line of sight. The routes of subjects 6, 7, and 11 were compared with those of subjects 12, 13, and 17. Subjects 6 and 12 had map board A, subjects 7 and 13 had B, and subjects 11 and 17 had D. However, subjects 6, 7, and 11 had line of sight information whereas 12, 13, and 17 did not. Thus a comparison of similar situations with and without intervisibilities information was effected.

3) Target weapon. Notice from Table 15 that the following routes involved attacking a 14.5mm target: 6R1, 7R1, 8R1, 9R1, 12R1, 13R1 (routes 10R1 and 14R1 were omitted from this analysis since the subject plots were missing from the rankings of subjects 10 and 14). On the other hand, routes 6R2, 7R2, 8R2, 9R2, 11R1, 12R2, 13R3, and 17R1 attacked a 23mm target. Thus, the two categories just described were tabulated and compared to determine if the factor of the specific weapon attacked made a significant difference.

4) Map board (retabulated). The entire procedure for both the weighted and unweighted individual ranking functions was repeated, deliberately omitting the subject-plots in each case (thus for each subject two groups of six items each were ranked: e.g., Rt. 1-RF-AT, Rt 1-RF-M1, Rt 1-RF-M3, Rt 1-HF-AT, Rt 1-HF-M1, Rt 1-HF-M3). The reason for doing so was to be able to take advantage of the data provided by subjects 10 and 14. The reader will note from Table 15 that subjects 6 and 12 had map board A; 7, 9, and 13 had B; 8, 10,

and 14 had C; and 11 and 17 had D. Thus those four categories were tabulated and compared to see if the effect of the map board was significant.

5) Line of sight (retabulated). Computations similar to those in (2) above were made with the retabulated rankings. At a sacrifice of omitting the subject plots from this ranking, two further rankings could be included in the analysis. Thus the routes of subjects 6, 7, 10, and 11 were compared with those of subjects 12, 13, 14, and 17.

It should be noted that each of the analyses performed above was done according to both the weighted and unweighted formats. A summary of the factorial analysis schemes is presented in Table 23.

Results

Table 24 presents the numerical scores and ranking awarded to each route by each subject. The numerical scores were provided by the subjects and the rankings were of course derived from the scores. The reader should bear in mind that the rankings presented below constitute the basis of the analyses to follow.

The results of the various analyses can now be stated. The overall rankings obtained by combining the rankings of all but subjects 10 and 14 are shown in Tables 25 and 26.

Table 23

Factorial Analysis Schemes

Comparison	Nature	Routes	Description
1	Route	Rte. 1, Subj. 6,7,8, 9,11,12,13,17 vs. Rte. 2, Subj. 6,7,8, 9,11,12,13,17	Compares overall effect of route 1 to overall effect of route 2
2	Line of sight	Subj. 6,7,11 (Rtes. 1 & 2) vs. Subj. 12,13,17 (Rtes. 1 & 2)	Compares subjects with line of sight information to those without
3	Target weapon	Subj. 6,7,8,9,12,13 (Rte. 1) vs. Subj. 6,7,8,9,12,13 (Rte. 2), 11,17 (Rte. 1)	Compares effect of attacking 14.5mm with effect of attacking 23mm
4	Map board (re-tabulated)	Subj. 6,12 (Rtes. 1 & 2) vs. Subj. 7,9,13 (Rtes. 1 & 2) vs. Subj. 8,10,14 (Rtes. 1 & 2) vs. Subj. 11,17 (Rtes. 1 & 2)	Compares effects of the four map boards
5	Line of sight	Subj. 6,7,10,11 (Rtes. 1 & 2) vs. Subj. 12,13,14,17 (Rtes. 1 & 2)	Same as (2) above

Table 24

Fort Ord Route Score

Route	Subj. 6		Subj. 7		Subj. 8		Subj. 9		Subj. 10		Subj. 11		Subj. 12		Subj. 13		Subj. 14		Subj. 17	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Rte. 1 Subj.	99	2	100	1	100	1	100	1	X	X	75	3	92	4	70	5	X	X	100	1
RF AT	80	4	99	2	90	2	40	4	40	3	100	1	98	3	100	1	95	2	80	4
RF M1	0	7	0	7	70	4	90	2	50	2	75	3	40	5	80	4	70	4	77	5
RF M3	75	5	75	4	90	2	40	4	35	4	75	3	98	3	50	6	95	2	75	6
HF AT	100	1	97	3	50	5	40	4	20	6	90	2	100	1	100	1	75	3	98	2
HF M1	25	6	65	5	89	3	40	4	100	1	100	1	40	5	95	2	50	5	95	3
HF M3	95	3	10	6	50	5	80	3	30	5	100	1	99	2	94	3	100	1	95	3
Rte. 2 Subj.	99	2	75	4	100	1	80	4	X	X	75	5	100	1	100	1	X	X	100	1
RF AT	100	1	0	7	10	5	85	3	100	1	80	4	98	3	85	4	10	4	95	2
RF M1	35	5	10	6	95	2	25	6	45	4	97	2	30	7	70	5	0	5	0	3
RF M3	40	4	96	3	50	3	90	2	25	5	100	1	40	6	100	1	25	3	0	3
HF AT	95	3	97	2	20	4	40	5	60	3	90	3	99	2	90	3	0	5	0	3
HF M1	25	6	65	5	95	2	40	5	65	2	100	1	70	4	60	6	100	1	0	3
HF M3	0	7	100	1	20	4	100	1	15	6	90	3	60	5	90	2	95	2	0	3

Table 25

Unweighted Ranking

1. Subject
2. Hover fire acid test
3. Hover fire model 3
3. Running fire acid test
4. Running fire model 3
5. Hover fire model 1
6. Running fire model 1

Table 26

Weighted Ranking

Ranking	Value
1. Subject	1 1
2. Hover fire acid test	2.102×10^5
3. Running fire acid test	2.360×10^5
4. Running fire model 3	5.518×10^5
5. Hover fire model 1	3.935×10^6
6. Hover fire model 3	6.582×10^9
7. Running fire model 1	1.092×10^{15}

The reader will recall that numerical scores were obtained for the weighted analysis by multiplying corresponding entries of the various ranking matrices involved. For the purpose of having a uniform comparison standard, the subject plot was arbitrarily selected. Thus for example if one were given the ranking matrix

$$\begin{array}{c} \\ S \\ AT \\ M1 \\ M3 \end{array}
\begin{array}{c} \begin{array}{cccc} S & AT & M1 & M3 \end{array} \\
\begin{pmatrix} 1 & 1.01 & 4 & 4 \\ .99 & 1 & 3.99 & 3.99 \\ .25 & .23 & 1 & 1 \\ .25 & .23 & 1 & 1 \end{pmatrix} \end{array}$$

one would deduce the ranking

1. S
2. AT
3. M1
3. M3

by inspecting the values in any row. Thus, for example one could associate the numbers in the row marked S (or any other, for that matter) with the deduced ranking. The associated ranking would be the same in any case. Using row S one would have:

Rank	Value
1. S	1
2. AT	1.01
3. M1	4
3. M3	4

The values thus presented would represent the ranking of each of the routes <u>relative to</u> the subject route.

The convention to be followed throughout this report will be the following: in the case of the weighted ranking tabulations, if the subject route enters the analysis, the numerical values will always be those which are obtained relative

to the subject route. In the cases in which the subject route is omitted, the ranking values will be relative to running fire acid test. The reader will undoubtedly recognize that the choices are quite arbitrary. However, at least in the cases in which a subject route exists for comparison they are not totally without foundation, i.e., the assumption is reasonable that the subject would prefer to use his own route for a uniform paired comparison standard.

A few words should be said about the overall ranking results. Notice that the unweighted (ordinal) and weighted rankings are quite similar. In fact the only difference is that hover fire model 3 moves from position 3 (tied with running fire acid test) to position 6. A plausible explanation of this change of location is that hover fire, model 3, was generally fairly highly ranked by the subjects, but that two or three of them found that it produced a highly impractical route. A glance at Table 24 would tend to confirm the above remarks. Notice also that the subject route was uniformly preferred to the others.

The relative ranking values are also rather revealing. The reader will recall that a slight modification of the rankings provided by the subjects was made: namely, a subject score of zero for a route was arbitrarily changed to 10^{-3}. Thus if a subject gave route S a score of 100, and route RF-M1 a score of zero, the associated relative ranking would be $M(S, RF\text{-}M1) = 100/10^{-3} = 10^5$. It is quite unlikely that products of the order of magnitude of 10^5 would result unless at least one subject scored the second of the paired routes zero. Thus inspection of Table 26 suggests that at least one subject regarded each route as absolutely valueless. A glance at Table 24 indeed confirms this suspicion. A

A more detailed look at the results will be provided by the factor analyses contained in Table 27 through 31.

Tables 26 through 31 clearly show that the preference rankings are far from unanimous. In fact, in looking at Tables 27 to 31 one might wonder if any discernible patterns of consensus are present, or if the rankings therein presented reveal only incoherent variation (noise). Clearly some sort of statistical methodology is required to test hypotheses regarding adequacy of ranking. The one to be employed here is the pairwise application of a sign test discussed on pp. 16-8 to 16-9 of National Bureau of Standards Handbook #91, Experimental Statistics by M. G. Natrella. Briefly, the test is a two-sided one to determine if two products (processes, routes, etc.) differ in average performance. Suppose, for example, that two routes designated A and B were given the following numerical scores by the various subjects:

Subject	A	B	A/B
6	99	87	+
7	45	72	-
8	83	24	+
9	96	96	X
10	36	40	-
11	72	60	+
12	59	35	+
13	92	19	+
14	81	73	+
17	52	27	+

The entries in the column designated A/B are obtained by comparing the values given in column A with the respective values appearing in column B: a plus sign

Table 27

Comparison of Route 1 Responses with Route 2 Responses

Route 1 - Unweighted	Route 2 - Unweighted	Route 1 - Weighted	Value	Route 2 - Weighted	Value
1. S	1. S	1. S	1.000	1. S	1.000
2. R1-HF-AT	2. R2-HF-AT 2. R2-RF-M3 2. R2-HF-M3	2. R1-RF-AT	2.140	2. R2-RF-M3	6.443×10^4
3. R1-RF-AT		3. R1-HF-AT	2.793	3. R2-HF-AT	7.528×10^4
4. R1-HF-M3	3. R2-RF-AT	4. R1-RF-M3	8.564	4. R2-RF-AT	1.103×10^5
5. R1-HF-M1	4. R2-HF-M1	5. R1-HF-M3	14.225	5. R2-HF-M1	1.719×10^5
6. R1-RF-M3	5. R2-RF-M1	6. R1-HF-M1	22.889	6. R2-RF-M1	2.632×10^6
7. R1-RF-M1		7. R1-RF-M1	4.15×10^8	7. R2-HF-M3	4.627×10^8

Table 28

Line of Sight Comparisons: Subjects 6, 7, 11 Vs. Subjects 12, 13, 17

6,7,11 - Unweighted	12,13,17 - Unweighted	6,7,11 - Weighted	Value	12,13,17 - Weighted	Value
1. HF-AT	1. HF-AT	1. HF-AT	.570	1. S	1
2. S	2. S	2. S	1	2. RF-AT	1.037
3. HF-M3	3. RF-AT	3. RF-M3	2.551	3. HF-AT	7.370×10^3
4. RF-AT	4. HF-M3	4. HF-M1	15.656	4. HF-M3	1.348×10^4
5. RF-M3	5. HF-M1	5. RF-AT	8.708×10^3	5. HF-M1	4.248×10^4
6. HF-M1	6. RF-M3	6. HF-M3	4.881×10^4	6. RF-M3	4.380×10^4
7. RF-M1	7. RF-M1	7. RF-M1	1.640×10^9	7. RF-M1	1.245×10^5

Table 29

Line of Sight Comparison, Recomputed, Excluding Subject Plot: Subjects 6, 7, 10, 11 Vs. Subjects 12, 13, 14, 17

6, 7, 10, 11 - Unweighted	12, 13, 14, 17 - Unweighted	6, 7, 10, 11 - Weighted	Value	12,13,14,17 - Weighted	Value
1. RF-AT	1. HF-AT	1. HF-AT	2.832×10^{-4}	1. HF-M3	.137
2. HF-AT	2. HF-M3	2. HF-M1	9.594×10^{-4}	2. HF-M1	.819
3. HF-M1	3. RF-AT	3. RF-M3	1.717×10^{-3}	3. RF-AT	1.000
4. RF-M1	4. HF-M1	4. RF-AT	1.000	4. RF-M3	1.777
5. RF-M3	5. RF-M3	5. HF-M3	65.844	5. HF-AT	9.474×10^{3}
5. HF-M3	6. RF-M1	6. RF-M1	5.582×10^{4}	6. RF-M1	1.712×10^{5}

Table 30

Target Weapon Comparisons: 6, 7, 8, 9, 12, 13 (Rte. 1), Vs. 6, 7, 8, 9, 12, 13 (Rte. 2), 11, 17 (Rte. 1) or 14.5 mm Alternatives Vs. 23 mm Alternatives

14.5mm - Unweighted	23mm - Unweighted	14.5mm - Weighted	Value	23mm - Weighted	Value
1. S	1. S	1. S	1	1. S	1
2. HF-AT	2. HF-AT	2. RF-AT	2.283	2. HF-AT	7.7
3. RF-AT	3. HF-M3	3. HF-AT	3.287	3. RF-M3	11.48
4. HF-M3	4. RF-AT	4. RF-M3	6.425	4. HF-M1	18.32
5. RF-M3	5. RF-M3	5. HF-M3	18.029	5. RF-M1	442
6. HF-M1	6. HF-M1	6. HF-M1	29.010	6. HF-M3	4.38×10^3
7. RF-M1	7. RF-M1	7. RF-M1	3.195×10^6	7. RF-AT	1.046×10^4

Table 31

Map Board Comparisons, Recomputed: 6, 12 Vs. 7, 9, 13 Vs. 8, 10, 14 Vs. 11, 17

6, 12 - Unweighted Map Board A	7, 9, 13 - Unweighted Map Board B	8, 10, 14 - Unweighted Map Board C	11, 17 - Unweighted Map Board D
1. HF-AT	(1. HF-AT (1. HF-M3	1. HF-M1	1. HF-M1
2. RF-AT	(2. RF-AT (2. RF-M3	2. RF-AT	2. HF-M3
3. HF-M3	3. HF-M1	3. RF-M3	3. HF-AT
4. RF-M3	4. RF-M1	4. RF-M1	4. RF-AT
5. HF-M1		5. HF-M3	5. RF-M1
6. RF-M1		6. HF-AT	6. RF-M3

6, 12 Weighted	Value	7, 9, 13 Weighted	Value	8, 10, 14 Weighted	Value	11, 17 Weighted	Value
1. HF-AT	.817	1. HF-AT	2.049×10^{-4}	1. HF-M1	.012	1. RF-AT	1.000
2. RF-AT	1.000	2. RF-M3	2.119×10^{-4}	2. RF-M3	.366	2. HF-M1	$.674 \times 10^{3}$
3. RF-M3	6.535	3. HF-M3	4.228×10^{-4}	3. HF-M3	.800	3. HF-M3	$.748 \times 10^{3}$
4. HF-M1	43.904	4. HF-M1	4.829×10^{-4}	4. RF-AT	1.000	4. HF-AT	$.806 \times 10^{3}$
5. HF-M3	1.361×10^{4}	5. RF-AT	1.000	5. RF-M1	3.266×10^{3}	5. RF-M3	1.138×10^{3}
6. RF-M1	2.287×10^{5}	6. RF-M1	2.293	6. HF-AT	3.801×10^{4}	6. RF-M1	1.142×10^{3}

is entered if the entry in column A exceeds that in column B. If the entry in B exceeds that in A, a minus sign is recorded. In case the two entries are equal, a large X is entered in column A/B. Notice that there are ten pairs of numbers, nine of which produce either a plus or a minus in column A/B. Referring to Table A-33 of NBS handbook 91, one sees that rejection of the hypothesis that A and B are not significantly different at the .10 level requires that eight or more plus signs appear in column A/B. At the .25 level one would reject the hypothesis based on the appearance of seven or more plus signs. Thus one would reject the hypothesis at the .25 level but not at the .10 level.

All of the pairwise analyses to be discussed below follow precisely the format just outlined. In each case the significance level was taken to be .10.

Tables 32 and 33 exhibit the basic raw data from which the rank tests were made. The entries in the cells of Table 32 were obtained as follows. There are $\binom{7}{2} = 21$ pairs of plots which can be formed from the basic seven model and subject plots, i.e., RF-AT, HF-AT, RF-M1, HF-M1, RF-M3, HF-M3, and the subject plots. Those pairs are represented across the top of Table 32 where a pair has an upper plot and a lower plot, e.g., the pair $\frac{\text{S}}{\text{RAT}}$ would consist of the subject plot as an upper plot and the running fire acid test plot as the lower plot. In each case the entry in a cell was obtained by comparing the upper plot with the lower plots, using the entires contained in Table 24. Thus, for example $\frac{\text{S}}{\text{RAT}}$ (rte. 1 - subj. 6) is a comparison of the subject plot vs. the running fire acid test plot for subject 6, route 1. Referring to Table 24, one sees that the subject plot in that case was given a rating of 99, whereas

Table 32

Model-Subject Paired Comparisons

	S RAT	S R1	S R3	S HAT	S H1	S H3	RAT R1	RAT R3	RAT HAT	RAT H1	RAT H3	R1 R3	R1 HAT	R1 H1	R1 H3	R3 HAT	R3 H1	R3 H3	HAT H1	HAT H3	H1 H3
Rte. 1-6	+	+	+	-	+	+	+	+	-	+	-	-	-	-	-	-	+	-	+	+	-
7	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	+	+	+	+	+
8	+	+	+	+	+	+	+	X	+	+	+	-	+	-	+	+	+	+	-	X	+
9	+	+	+	+	+	+	-	X	X	X	-	+	+	+	+	X	X	-	X	-	-
10	X	X	X	X	X	X	-	+	+	-	+	+	+	-	+	+	-	+	-	-	+
11	-	X	X	-	-	-	+	+	+	X	X	X	-	-	-	-	-	-	-	-	X
12	-	+	-	-	+	-	+	X	-	+	-	-	-	X	-	-	+	-	+	+	-
13	-	-	+	-	-	-	+	+	X	+	+	+	-	-	-	-	-	-	+	+	+
14	X	X	X	X	X	X	+	X	+	+	-	-	-	+	-	+	+	-	+	-	-
17	+	+	+	+	+	+	+	+	-	-	-	+	-	-	-	+	-	-	+	+	X
Rte. 2-6	-	+	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+	+	+	+	+
7	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-
8	+	+	+	+	+	+	-	-	-	-	-	+	+	X	+	+	-	+	-	X	+
9	-	+	-	+	+	-	+	-	+	+	-	-	-	-	-	+	+	-	X	-	-
10	X	X	X	X	X	X	+	+	+	+	+	+	-	-	+	-	-	+	-	+	+
11	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	X	+	-	X	+
12	+	+	+	+	+	+	+	+	-	+	+	-	-	-	-	-	-	-	+	+	+
13	+	+	X	+	+	+	+	-	-	+	-	-	-	+	-	+	+	+	+	X	-
14	X	X	X	X	X	X	+	-	+	-	-	-	X	-	-	+	-	-	-	-	+
17	+	+	+	+	+	+	+	+	+	+	+	X	X	X	X	X	X	X	X	X	X

Table 33

Model-Factor Paired Comparisons

	S/ RAT	S/ R1	S/ R3	S/ HAT	S/ H1	S/ H3	RAT/ R1	RAT/ R3	RAT/ HAT	RAT/ H1	RAT/ H3	R1/ R3	R1/ HAT	R1/ H1	R1/ H3	R3/ HAT	R3/ H1	R3/ H3	HAT/ H1	HAT/ H3	H1/ H3
Overall	+	+	+	+	+	+	+	+	-	+	+	-	-	-	-	-	+	+	+	+	+
Rte. 1	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	+	+	+	+	-
Rte. 3	+	+	+	+	+	+	+	-	-	+	+	-	-	-	+	+	+	+	+	+	+
6-7-11 LOS	+	+	+	-	+	+	+	-	-	-	+	-	-	-	-	-	+	+	+	+	+
12-13-17 LOS	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+	+	-
6-7-10-11 LOS							+	-	-	-	+	-	-	-	-	-	-	+	+	+	+
12-13-14-17 LOS							+	+	+	-	-	-	-	-	-	+	-	-	-	-	-
14-5	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	+	+	+	+	-
23	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	-	+	+	+	+	+
A							+	+	-	+	+	-	-	-	-	-	+	+	+	+	+
B							+	-	-	-	-	-	-	-	-	-	+	+	+	+	-
C							+	-	+	-	-	-	+	-	-	+	-	+	-	-	+
D							+	+	+	+	+	-	-	-	-	-	-	-	-	-	+
	↑ S/ RAT	↑ S/ R1	↑ S/ R3		↑ S/ H1	↑ S/ H3	↑ RAT/ R1					↑ R3/ R1	↑ HAT/ R1	↑ H1/ R1	↑ H3/ R1	↑ HAT/ R3		↑ R3/ H3		↑ HAT/ H3	

the running fire and test plot was given a score of 80. Since 99-80 is greater than zero, an entry of plus was recorded in the $\overset{\mathrm{S}}{\mathrm{RAT}}$ (rte. 1 - subj. 6) cell. A similar exercise was performed to obtain Table 33. However, in Table 33, composite rankings were encoded, rather than individual rankings. The composite rankings which were utilized were the weighted rankings in each case.

First, statistical analyses were performed to determine the significance of the components within the various rankings. For instance, the overall ranking (Table 26) combines sixteen component rankings, namely rte. 1 - subj. 6, 7, 8, 9, 11, 12, 13, 17; rte. 2 - subj. 6, 7, 8, 9, 11, 12, 13, 17. Thus for each pair of routes there are sixteen pairs of numbers which result in a column of sixteen plus, minus, or X symbols. The columns of symbols were analyzed to determine significance (or lack thereof). The results of the analysis are specified below.

<u>Overall ranking</u>. The subject plot was significantly preferred to each of running fire route 1, hover fire route 1. The running fire acid test route was significantly preferred to running fire route 1; likewise hover fire route 1 was significantly preferred to running fire route 1. In all other cases, either a significant difference was not detected or there were insufficient samples to make a determination. Pictorially, the statistical analysis of the overall ranking can be represented as a partial order:

$$
\begin{tikzcd}
\mathrm{S} \arrow[d] & \\
\mathrm{HF\text{-}M1} \arrow[d] & \mathrm{RF\text{-}AT} \arrow[dl] \\
\mathrm{RF\text{-}M1} &
\end{tikzcd}
$$

<u>Route 1 ranking</u>. RF-AT was significantly preferred to RF-M1. No other significance was observed.

Route 3 rankings. S was significantly preferred to RF-M1 and HF-M1.

Line of sight - subjects 6, 7, 11. RF-M3 was significantly preferred to RF-M1.

Line of sight - subjects 12, 13, 17. RF-AT was significantly preferred to RF-M1; HF-AT was significantly preferred to RF-M1 and to HF-M1; HF-M3 was significantly preferred to RF-M1.

Line of sight, retabulated - subjects 12, 13, 14, 17. RF-AT was significantly preferred to RF-M1; HF-M3 was significantly preferred to RF-M1.

Weapon alternative 14.5mm. RF-AT was significantly preferred to HF-M1.

Weapon alternative 23mm. S was significantly preferred to RF-M1 and HF-M1; HF-AT was significantly preferred to RF-M1.

Map board A. Insufficient data existed to make a statistical determination.

Map board B. No significant differences were detected.

Map board C. Insufficient data existed to make a statistical determination.

Map board D. No significant differences were detected.

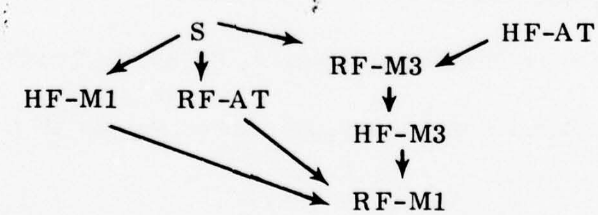
The reader should be cautioned that the statistical procedure employed to obtain the above results, being distribution free, is not very powerful. Because a significant difference was not detected in the relative value of a pair of routes, it is by no means necessarily the case that a significant difference would not emerge if enough subjects were polled. If the entire population of

U.S. Army helicopter pilots were sampled, doubtless more definitive statements could be made. Lack of significance can be attributed to one of three factors: 1) too small a sample, 2) too many ties (more than 20% render the particular test employed useless), or 3) genuine failure of the test to reveal significance. For a significant difference to be detected, there must be many more plus signs than minus signs (or vice versa). In many cases, due to the small sample sizes, significance could not be asserted without unanimous agreement, for instance. One should regard the cases wherein significance was not detected as open problems. That is, from a philosophical point of view one can make no definitive statement based on the small samples taken as to whether there would be a true consensus among the pilot population as a whole with respect to a given pair of routes, or not.

If one accepts the rankings presented in Tables 26 through 31 as being reasonable measures of consensus, one can perform a somewhat more interesting analysis. Table 33, as mentioned earlier, was obtained by encoding the preference rankings of the weighted analyses presented in Tables 26 through 31. Of course, some of the information will be redundant due to the fact that each of the rankings in Tables 26 through 31 was obtained by combining a given subset of the set of subject responses for routes 1 and 2. Nevertheless, according to table A-33 of <u>NBS Handbook 91</u>, for paired samples of size 7, seven signs of the same type constitutes evidence for a significant difference in the pair of plots in question, at both the .05 and .10 significance level. That is, unanimity constitutes a statistical consensus at the .05 and .10 level. Likewise, for 13

paired samples ten or more outcomes of the same type constitutes a statistically significant consensus.

A glance at Table 33 reveals that of the first six columns, five exhibit the conditions sufficient for consensus: S/RFAT, S/RF-M1, S/RF-M3, S/HF-M1, S/HF-M3. Since these columns all contain plus signs one obtains the information that the subject plot is significantly preferred to RF-AT, RF-M1, RF-M3, HF-M1 and HF-M3. With respect to the remaining columns, RF-AT/RF-M1, RF-M3/HF-M3, and HF-HT/HF-M3 exhibit the sufficient property for statistical significance in terms of plus signs. In terms of minus signs RF-M1/RF-M3, RF-M1/HF-AT, RF-M1/HF-M1, RF-M1/HF-M3, and RF-M3/HF-AT exhibit statistical significance. Thus one can conclude that RF-AT, RF-M3, HF-AT, HF-M1, and HF-M3 are all preferred to RF-M1; that HF-AT is preferred to RF-M3; and that RF-M3 and HF-AT are both preferred to HF-M3. The above results can be represented diagrammatically by the following partial order:



No definitive statements can be made about relationships between the remaining pairs.

The reader is urged to refer to Table 26. Note that the above partial order is consistent with the strict linear order of Table 26 in the following

sense: take any chain in the partial order (i.e. any directed sequence of arrows with associated nodes (plots in this case). Then that chain is also a chain in the linear order of Table 26. For instance

$$\begin{array}{c} HF\text{-}AT \\ \downarrow \\ RF\text{-}M3 \\ \downarrow \\ HF\text{-}M3 \\ \downarrow \\ RF\text{-}M1 \end{array}$$

is a chain in both the above partial order and in Table 26. The fact of consistency of partial orderings may not in itself be particularly surprising. However, the fact that such a large number of the pairings (over half) exhibit compatible results, statistically speaking, is highly interesting.

The foregoing analyses constitute a sort of distribution-free analysis of variance. In that context one discerns the following pattern: within each factor there is considerable individual variation (few statistically significant paired differences were observed); however, the average rankings of the factors manifested a remarkable consistency, as seen by the partial ordering shown above.

In conclusion, some general qualitative observations should be made. One of the interesting problems considered in the overall experiment was whether the absence of line-of-sight information made any difference in the subject responses. There is some evidence that it did. Notice (Table 24) that subject 17 ascribed a rank of zero to all plots except his own and the running fire acid test

plot. Subject 17 was required to attack a target known to be a REDEYE in his route 2 plot. Pictorially, the situation with which he was confronted was analogous to Figure 35:

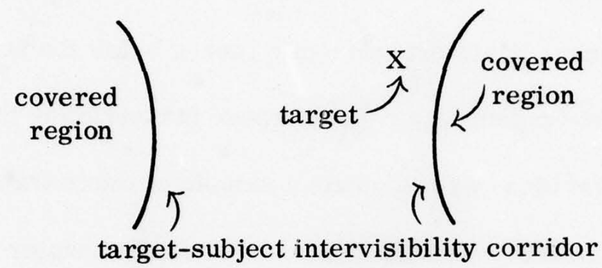


Figure 35

That is, it was possible for the subject to pass very close to the target without being intervisible. Every decision model except running fire acid test took advantage of that fact to bring the firer near the target via a totally covered route. Now of course subject 17 was not able to recognize that his approach would always be covered, since he was purposely denied the line of sight overlay. He, therefore, reasoned that each decision model except RF-AT would bring him dangerously close to an extremely lethal situation in an unacceptable fashion (namely, on a seemingly uncovered route). Thus he understandably exhibited absolutely no enthusiasm for the decision models except RF-AT.

In light of the response of subject 17, it might be well in future experimentation with the decision models to provide each subject with line-of-sight information. In a real combat situation the pilot would have an opportunity to study the actual terrain over which he would have to fly, and presumably the results of his study would be tantamount to having a line-of-sight overlay.

The results of chapter five of this report indicate that the pilots at Fort Rucker tended to favor decision model 1. The Fort Rucker results are clearly at variance with those presented in this chapter, wherein running fire - model 1, for instance, is almost uniformly ranked below the rest. There is, however, a plausible explanation. The purpose in conducting the Fort Ord experiment in the first place was to obtain a sample of pilots trained in mid-intensity warfare tactics. Now the reader will recall (Chapter 2) that decision Model 1 was described as modeling an extremely conservative behavior. Decision Model 1 places a uniformly high penalty on being exposed to a hostile weapon, regardless of the range. Decision Model 3, on the other hand, is less conservative; the exposure penalty is a function of the range as well as whether the pilot is covered or uncovered. The Acid Test Model is supposed to capture the flavor of the subject's individual subjective reaction to danger as a function of range, azimuth, exposure time, etc. Generally it is viewed as less conservative than either decision Model 1 or decision Model 3.

It is altogether likely that the difference in the results of the two experiments can be explained in terms of an experience factor. The Fort Ord pilots were used to mid-intensity antiaircraft evasion tactics, were familiar with the more lethal weapons, and would therefore logically be willing to accept a greater risk than would pilots not trained in mid-intensity warfare. Several subjects at Fort Rucker indicated verbally that the conservative decision model was more appealing to them in terms of results produced, even though it seemingly contradicted their own perceived threat functions (see Chapters 3 and 5).

On the other hand, the Fort Ord pilots seemed to find their perceived threat functions quite adequate—much better in fact than the more conservative decision models. Unfortunately there are no written or verbal comments from the Fort Ord subjects which confirm the conjecture that decision Model 1, in particular, was found to be too conservative. The reason for the preference of the Acid Test Model remains open to speculation. The best one can do is assert that there did turn out to be a correlation between the experience of the subjects with respect to mid-intensity warfare training and conservativeness of the decision model which they preferred, viz., the training made the pilots more aggressive.

CHAPTER 7

HELICOPTER ROUTE SELECTION MODEL (DYNFLITE)

by Gordon M. Clark

Introduction

This chapter presents an overall evaluation of the proposed route selection models and a specification of the model to be used in DYNFLITE. Recall that DYNFLITE is to be used in DYNTACS X for selecting helicopter attack routes. In addition, some observations are made concerning insights to the route selection decision process. Finally, recommendations are made concerning future research for DYNFLITE. More specifically, four questions are addressed in this chapter:

1. What is the best route selection model?
2. Has an acceptable route selection model been developed?
3. What are the DYNFLITE design specifications?
4. What future research should be performed?

Evaluation of Candidate Model Performance

An Important Qualification

Prior to evaluating the performance of the candidate route selection models, an important qualification must be made that applies to all conclusions drawn throughout this chapter. This qualification pertains to the Acid Test Model, defined in Chapter 3, which is an important candidate route selection

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THE HELICOPTER ROUTE SELECTION MODEL (DYNFLITE). (U)
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model. In fact this model is the most interesting in the respect that individual perceptions of threat in diverse situations are reflected in the model as input tactical doctrine. That is, the model attempts to quantify the threat perceptions of individual decision makers to a much higher degree than the other two models. The qualification assumes that the Acid Test Model as implemented in the route selection model of Chapter 2 accurately reflects decision-maker preferences concerning exposure to enemy threat. In Chapter 3 on page 112, a comparison was made showing that decision makers did not have additive disutilities as assumed in the route selection model. Thus, the routes selected employing the Acid Test Model may not be the preferred routes based upon the decision-maker inputs. In fact, the comparison in Chapter 3 indicates errors in threat calculations on the order of 100% are possible. However, all conclusions in this research assume that these errors will not effect the results since a revision to the dynamic programming algorithm was beyond the scope of the research.

Preferred Model

With the above qualification in mind, the preferred route selection model will be identified. As discussed in Chapter 5, the Fort Rucker experiments indicated that decision makers could be divided into two classes with respect to their preferences for a route selection model, i.e., those preferring Model One and those preferring some other model. Overall, the decision makers preferred Model One. This indicated that most decision makers used a very simple approach to evaluating routes, viz., minimization of total exposure time without regard

to target distance or azimuth. This preference for Model One shows that most decision makers of the Fort Rucker group responded differently in evaluating complete routes than they did in evaluating shorter route segments.

On the other hand, the Fort Ord decision makers preferred the Acid Test Model when a hover-fire was employed. In fact, the ratings for the hover-fire Aicd Test Model routes were not significantly different than the subject plots. This result shows that the route evaluations by the Fort Ord decision makers are consistent with their route segment evaluations. Since the Fort Ord decision makers were trained in mid-intensity combat, these experiments indicate that the Acid Test Model is the preferred route selection model, at least when employing hover fire.

When considering running fire, the Acid Test Model is preferred over Model One; however, the ratings for the Acid Test Model and Model Three were not shown to be significantly different. The general conclusion is that the Acid Test Model is preferred over the other two models. Of course, confidence in this conclusion could be increased with additional experimentation.

Acceptability of the Acid Test Model

Having chosen the Acid Test Model, the next step is to estimate the degree of acceptability of the model. That is, can the Acid Test Model take a decision maker's inputs specifying his threat perception or tactical doctrine and determine acceptable routes? The viewpoint used throughout this research is that the decision maker is the ultimate judge as to the acceptability of a

route and that the model routes are compared against the subject routes to judge their acceptability.

An acceptable route is defined as one giving a rating of 95 or above by a decision maker employing the rating rules of Chapter 4. That is, the model route is acceptable when consciously compared against the subject routes as the standard. Such a rating implies that the decision maker can find no definable fault in the route, and at the very worst would only slightly prefer his own route alternative to the one selected by the model. It would be desirable to restrict the definition of an acceptable route even further. However, it was noted in Chapter 5 that it may be very difficult to ever achieve higher average ratings because the population of decision makers may be biased against the model routes.

With this standard in mind, the Fort Ord R[illegible] are analyzed to estimate the acceptability of the Acid Test Models routes. The Fort Rucker results are regarded as biased estimates since the subjects were not trained in mid-intensity tactics. The Fort Ord Acid Test and Subject route ratings are shown in Table 34. Subject 10 data are deleted because of the error in the initial point of the subject routes noted in Chapter 6. Also, subject 12, 13, 14, and 17 data are deleted because those subjects did not have the advantage of line-of-sight overlays. Table 35 presents the averages for each model. Additional entries are labeled as Maximum-Acid Test, and these entries represent the maximum of the running fire and hover fire results in Table 34 for each subject. The motivation for taking the maximum of the running fireand hover fire ratings is

Table 34

Subject and Acid Test Model Ratings
(Fort Ord Experiment)

	Hover Fire Acid Test	Running Fire Acid Test	Subject
Subject 6 - Route 1	100	80	99
- Route 2	95	100	99
Subject 7 - Route 1	97	99	100
- Route 2	97	0	75
Subject 8 - Route 1	50	90	100
- Route 2	20	10	100
Subject 9 - Route 1	40	40	100
- Route 2	40	85	80
Subject 11 - Route 1	90	100	75
- Route 2	90	80	75

Table 35

Average Model Ratings
Fort Ord Data

Model	Adjusted for Subject as Standard	Average Score
Hover Fire - Acid Test	No	71.9
Running Fire - Acid Test	No	68.4
Maximum - Acid Test	No	82.1
Subject	No	90.3
Hover Fire - Acid Test	Yes	78.8
Running Fire - Acid Test	Yes	75.7
Maximum - Acid Test	Yes	90.9
Subject	Yes	100

to use the best Acid Test Model result over both firing tactics. Table 35 shows that the subject route has a higher average rating than the Acid Test Model Result. These average ratings were adjusted using the methodology of Chapter 6 so that the subject route is regarded as the standard. That is, the unadjusted average ratings were divided by .903 so that the average subject route rating is 100. On this basis, the hover fire - acid test rating becomes 78.8 and the running fire - acid test rating is 75.7. Also, the adjusted rating for the maximum acid test rating is 90.9. Referring to the rating scale definition presented on page 119, these Acid Test Model values ranging from 75.7 to 90.9 are in the third category where the subject's route is mildly preferred (on the average) to the Acid Test Model route and a specific reason for the preference can be cited.

Another viewpoint on the Acid Test Model acceptability is provided by enumerating the preferences shown in Table 34 for each subject. On the positive side, there are six out of ten cases where one of the Acid Test Model routes are preferred to the subject routes. On the other hand, subject seven rated the acid test - running fire route as worthless, i.e., a score of zero, for route 2. However, subject seven gave the acid test - hover fire route a rating of 97 which is better than the 75 for the subject route. The worst results were ratings of ten and twenty by subject eight on route 2.

The conclusion from this analysis is that the Acid Test Model can be regarded as acceptable for use in DYNTACS X; however, the results will not always be preferred to routes selected manually. In particular, recognition

must be given to the low Acid Test Model ratings given by the Fort Rucker subjects. On the other hand, sometimes the Acid Test Model routes will even be preferred to routes selected by a decision maker by his own admission. This conclusion must be qualified by stating that there is room for improving the model since the average Acid Test Model ratings are below the subject routes indicating a mild subject route preference.

DYNFLITE Design Specifications

Based upon the above results, the following specifications are made for DYNFLITE:

1. Use the Acid Test Model for comparing alternative routes.
2. Constrain the model so that hover fire can only occur from a covered position while flying knap-of-the-earth.
3. Include rise and fall time in order to obtain intervisibility with target for firing action.

Future Research

When considering future research in developing a helicopter route selection model, three problems with the Acid Test Model are important:

1. The existing dynamic programming algorithm, presented in Chapter 2, does not find the least threatening route.
2. The Acid Test Model did not rate high with the Fort Rucker subjects.
3. Some of the Fort Ord subjects rejected the Acid Test Model.

Ideally, a route selection model should be capable of taking decision-maker inputs and then constructing satisfactory routes for that decision maker.

Two improvements should be made in future experiments. First, the dynamic programming algorithm should be modified to find the least threatening route for the decision-maker inputs obtained in these experiments. In addition, the Phase I experiments should include additional questions to indicate how decision makers perceive threat when multiple route segments are considered with diverse target azimuths and range. These improvements may produce a model which generates routes that are acceptable to almost all decision makers, and some decision makers may even prefer the model routes to their own routes.

The Route Planning Decision Process

As indicated at the beginning of this report, very little was actually known about the route planning decision process when the research program was initiated. In Chapter 1, it was noted that quite a few route planning models have been developed and have been used in simulations of combat operations. However, the only model known to have been the object of a validation effort is the DYNTACS X ground unit route selection model (Shrive, 1976). Thus, the characteristics of the decision process itself have remained a mystery.

Furthermore, very little was actually known about the characteristics of the military decision-maker, at least with respect to his behavior in a complex decision under pressure of the type represented by the route planning

task. Studies of firing decisions conducted by researchers such as Olson (1970) and Parry (1971) had shed some light on these characteristics, but it was unknown whether the results were applicable in the more complex route planning task.

From the above observations it would appear that practically any information about the route planning decision process would represent an improvement over the situation that existed at the start of the research program. Therefore, it would have been almost impossible for the program to have totally failed in this respect. However, it would also be unlikely that the program could yield total knowledge of the decision process and the characteristics of the decision-makers involved.

Information about the decision process itself has been gathered from two sources. First, as discussed in Chapter 5, a major source of information was the set of comments offered by the subjects during the route evaluation session of Phase II and the answers provided by the subjects to questions posed in the Master Information Form and Critique administered during Phase I. The other major source of information was the ratings given to route alternatives during Phase II and Trial Two. From these ratings various characteristics of the process can be imputed. Unfortunately, the research program has not been designed as a psychophysical study to concentrate directly on any particular facet of the decision process, save for the threat assessment exercises conducted during Phase I. Consequently, conclusions about the decision process are mainly of a qualitative nature. Nevertheless, it is felt that this type of result is still valuable.

To repeat the summary presented in Chapter 5, subject comments and questionnaire responses indicate that pilots select their routes to minimize exposure to enemy weapons and maximize the element of surprise during an attack. During enroute travel they fly as close to the ground as possible and will go to any length to avoid being intervisible with the enemy. If intervisibility is unavoidable they try to choose a path that is as short as possible and as far as possible from the enemy weapon. For some, even an exposure time that is less than the reaction time of the enemy weapon is considered dangerous.

Proceeding further, pilots obviously consider the planning of the firing activity to be the most important aspect of preparing a route plan. They have very definite and fairly consistent criteria for selecting a mode of fire to employ in a given tactical situation. The same can be said for the criteria they use in selecting a hover fire position. For example, the subjects apparently favor hover fire over running fire unless they are forced into a duel by some factor such as terrain (lack of covered approaches) or weapon effective range (their own versus the enemy's). They apparently would prefer to deliver fire from a hover fire position outside the range of the enemy weapon if possible. Furthermore, in choosing a hover fire position they seek a masked avenue of approach from which they may "pop up" to fire. However, they try to avoid being silhouetted against the sky from this position.

From the above summary it is obvious that the subjects apparently agree with the assumptions that were made in developing the route planning model in general. Thus, the results summarized in the preceding sections of this chapter are certainly reasonable.

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APPENDIX A

LINE OF SIGHT MAPS

Introduction

A line of sight (LOS) map may be defined as a map showing areas over a battlefield in which a helicopter flying a knap of the earth flight profile would be intervisible with an enemy weapon located on the battlefield. As described in Chapter 2, such maps are of fundamental importance in the application of the route planning model to a route planning task. Therefore, in this appendix, a description of the methods used to construct LOS maps will be presented. Furthermore, the methods will be illustrated with material actually developed and used during the course of the research.

Problem Definition

Suppose that an enemy weapon is located at the point (XT, YT) within the area of a battlefield defined by the limits ($0 \leq XT \leq XMAX$) and ($0 \leq YT \leq YMAX$). By virtue of its position on the terrain, the weapon has an elevation ZT; and, if the height of the weapon is HT, then an observer located at (XT, YT) has an overall elevation

$$HLOS = HT + ZT. \tag{A.1}$$

Now, suppose helicopters flying knap of the earth are assumed to fly at one of two elevations above the terrain. Over open terrain this elevation is HOPEN, while over wooded regions the elevation is HOVER + HTREE where HTREE is the height of trees within the wooded area. If at a given position (XO, YO) the terrain has an elevation ZO, then the overall attitude of the helicopter flight path is

$$HFP = \begin{cases} ZO + HOVER + HTREE \text{ if } (XO, YO) \text{ is within a forest} \\ ZO + HOPEN \text{ otherwise.} \end{cases} \quad (A.2)$$

The point (XT, YT, HLOS) is said to be intervisible with the point (XO, YO, HFP) if and only if a straight line connecting the two points fails to intersect another line forming the profile of the terrain and the wooded areas between the two points as illustrated in Figure A.1. A LOS is said to exist if the two points are intervisible.

To construct a LOS map of the type used by the route planning model, one may simply specify the point (XT, YT, HLOS) as one point in the intervisibility relationship and then analyze all other points (XO, YO, HFP) for intervisibility, where $0 \leq XO \leq XMAX$, $0 \leq YO \leq YMAX$ and HFP is found by the relation A.2. Of course, in practice one would analyze only a finite number of points, perhaps a uniform grid of points covering the battlefield with each point separated from neighboring points by some interval Δ.

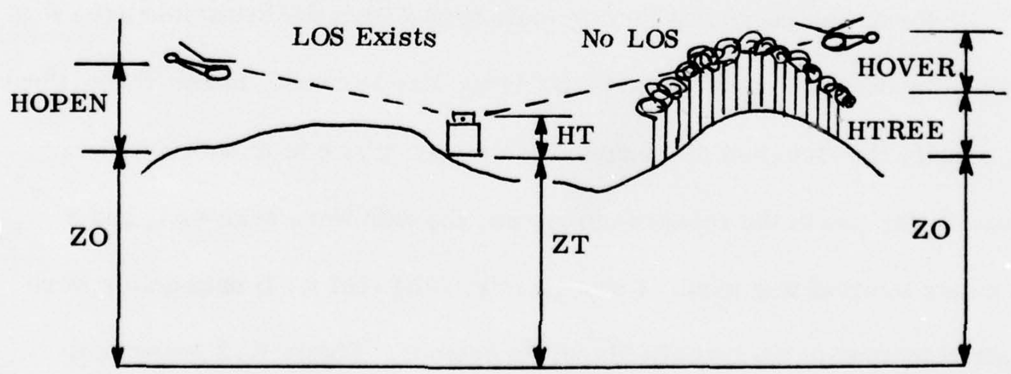


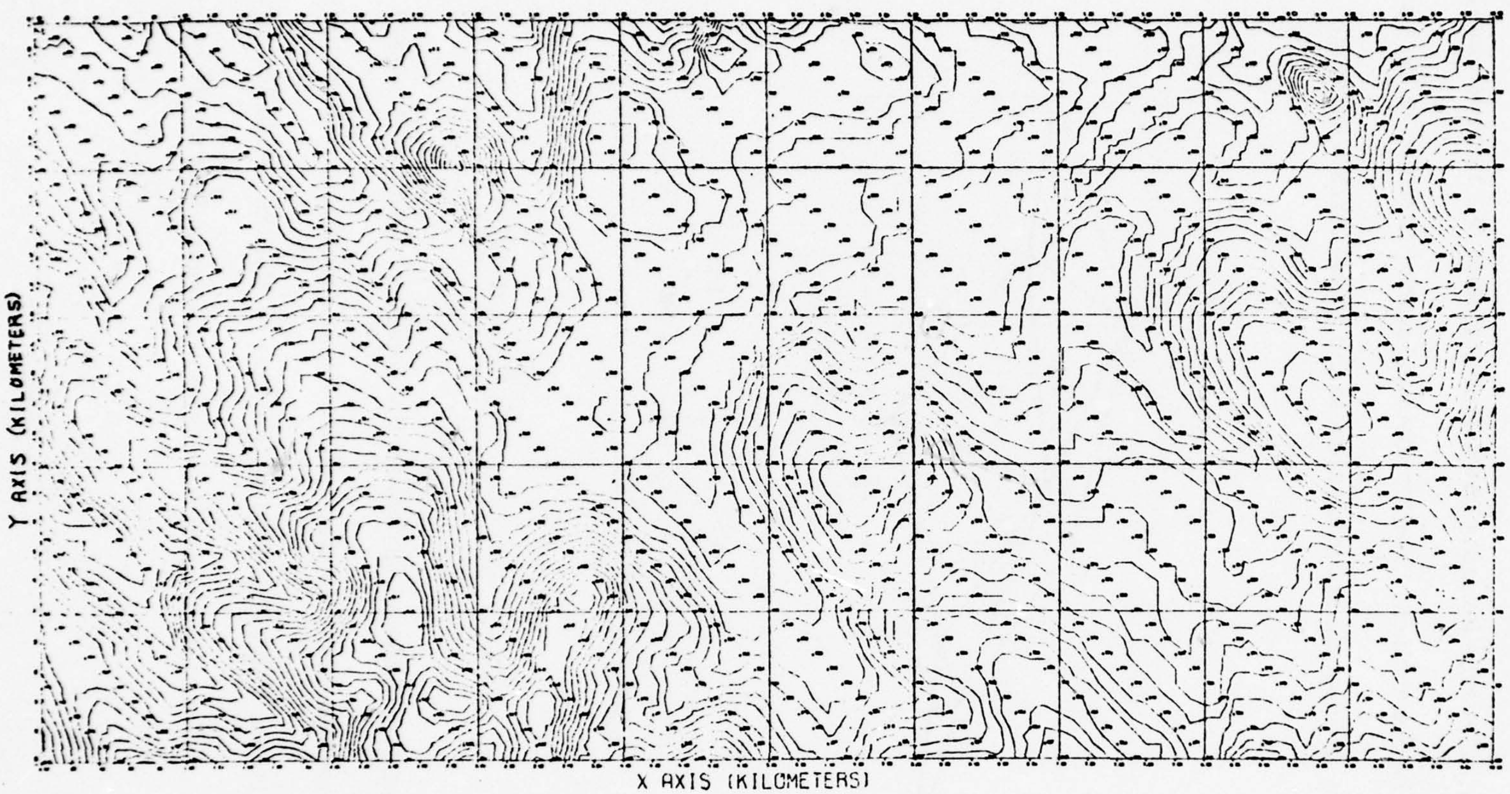
Figure A. 1. --Intervisibility Relationships

Application

For the research program it was decided to prepare LOS maps for an actual piece of terrain that would be representative of battlefields over which engagements of the type being studied could be expected to occur. Using this approach it was necessary to have a method for determining the elevation of the terrain at any battlefield position. It was also necessary that a method exist to determine whether or not a given point on the terrain is contained within the boundaries of a forested region. Finally, it was necessary to have a method for determining whether or not intervisibility exists between any two points of interest. The required methods are discussed in the following paragraphs.

Terrain.--The battlefield selected for use in the research program was a five by ten kilometer area from the Fulda Gap region of West Germany. Arbitrarily, XMAX was taken as the ten kilometer dimension.

Information regarding terrain elevations within the battlefield area was provided by data prepared by the U. S. Army Map Service. In raw form, these data specify the elevation of terrain at ten meter intervals in both X and Y. However, for use in the research program, the data were screened, and a 100 meter interval was used. Consequently, 5151 (101 x 51) data points were required to specify the battlefield terrain contour. Figure A.2 presents a contour map of the battlefield that was prepared by computer using the elevation data described above.



Original size of map: 7.5 x 14.5 inches

Figure A. 2. --Fulda Gap Contour Map

Now, the battlefield surface was represented as a continuous surface by the method illustrated in Figure A.3. This method, discussed in detail by Clark (1969a), allows the terrain elevation of any point (X, Y) within the battlefield area to be determined. The ten thousand planar surfaces in the shape of triangles give an adequate approximation to the actual terrain surface.

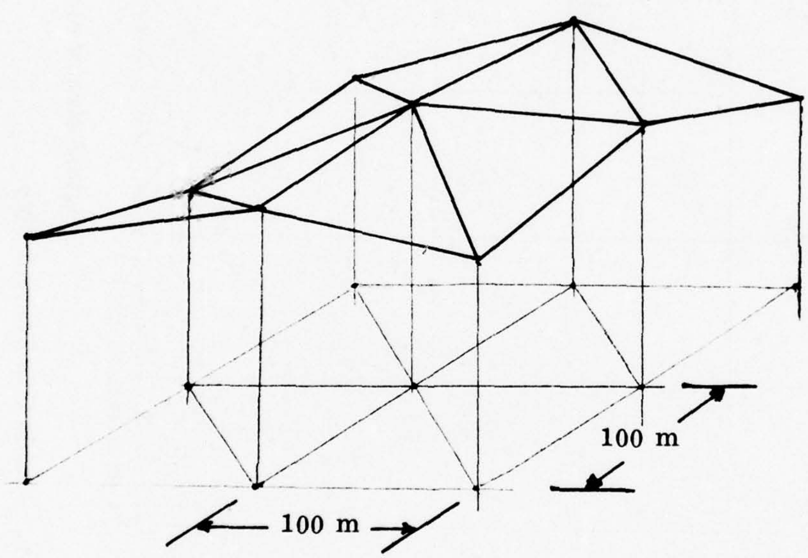


Figure A.3.--Terrain Representation

Forests.-- Situated throughout the selected battlefield area are forested regions composed of both conifer and deciduous vegetation. By photo interpretation techniques, Professor Olin W. Mintzer of The Ohio State University Department of Civil Engineering was able to determine that the average height

of trees within these forests is approximately twenty meters (HTREE = 20).[1] He was also able to accurately plot the boundaries of these forests within the battlefield area.

Using the data compiled by Professor Mintzer, a method was developed for representing forested regions within the simulated battlefield area. First, however, it was determined that the actual distribution of forested regions over the battlefield detracted from the overall worth of the area, at least as far as the research program was concerned. For example, in many areas too much of the terrain was covered by forested regions. More open terrain was desired to provide areas conducive to the conduct of armored operations.

Therefore, it was decided to slightly modify the actual boundaries of the forested regions in an attempt to enhance military characteristics of the terrain and hence to increase the value of the research. In certain areas forested regions were deleted to provide more open terrain for the reasons cited above. In other areas, forest boundaries were altered to better define avenues of approach to and fields of fire from positions that could be identified as key terrain.[2] Finally, the boundaries of the forested regions were simplified to

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[1]By private communication, Professor Mintzer stated that conifer vegetation was on the order of 50-60 feet in height while the older deciduous trees were approximately 60 feet tall. The forests are marked by uniform vegetation height.

[2]"Key terrain is any locality or area the control of which affords a marked advantage to either combatant. Key terrain must be seized, neutralized, or otherwise controlled to deny its use by the enemy or permit its use by friendly forces." Headquarters, Department of the Army, Armor Operations, FM 17-1, October 1966, p. 14.

facilitate their representation. The final result is indicated in Figure A.4.

The method used to represent forests is as depicted in Figure A.5. First, the battlefield is divided into fifty strips 100 meters wide and parallel to the X axis. The boundaries of the strips are then numbered from one to fifty-one starting with the boundary at Y = 0. Next, the presence or absence of forests along any strip boundary I forms intervals whose end points J are numbered from left to right with as many as four intervals being allowed (J = 1, 2, ..., 8). Such a limit was determined to be satisfactory by analyzing the modified forest boundaries shown in Figure A.4.

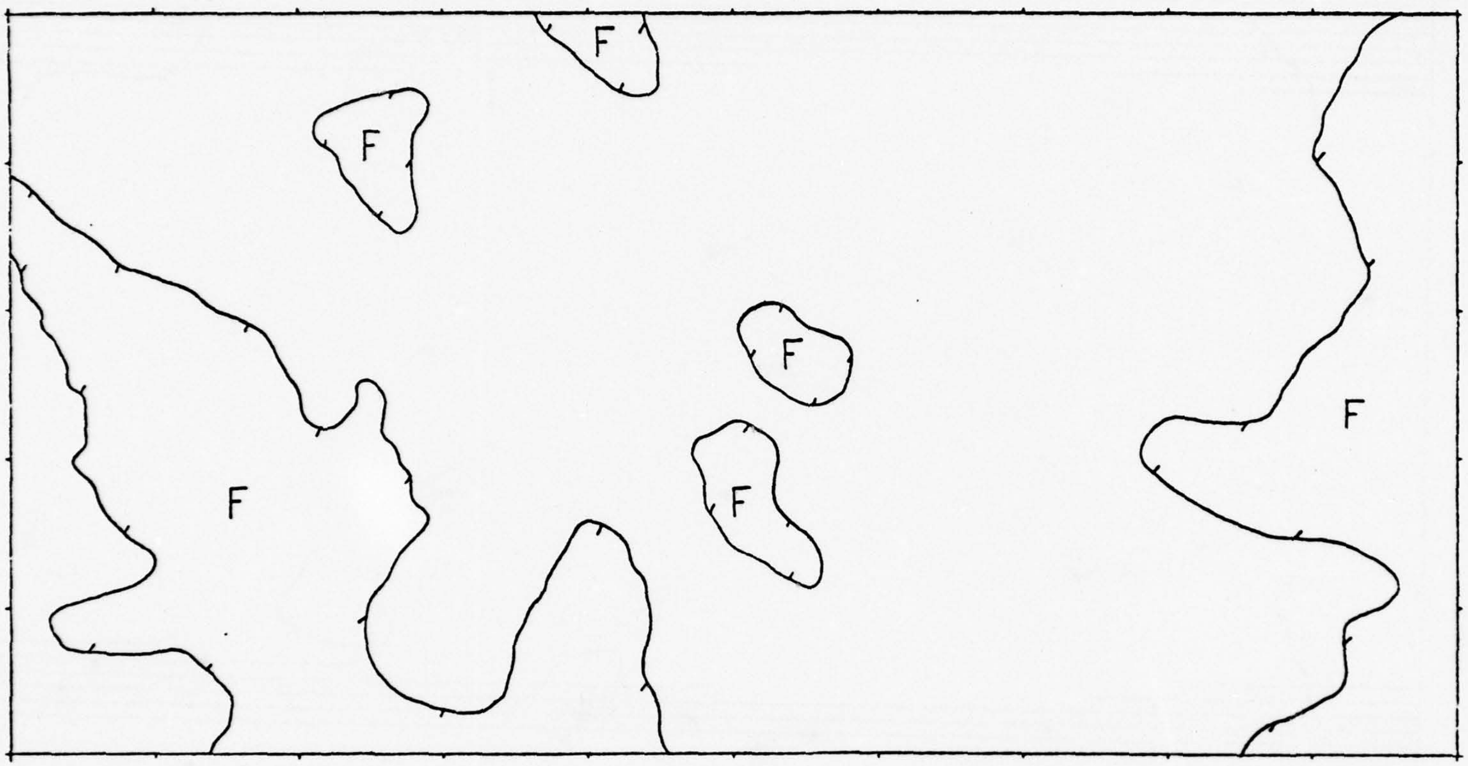
Finally, the X coordinates of the end points of intervals containing forests are recorded in the matrix IT(I, J) whose entries are defined as follows:

$$IT(I,\ J) = \left[\frac{X}{100} \right] + 1$$

where $[A]$ indicates the greatest integer equal to or less than A. Thus, the X coordinate of a given interval end point (I, J) can be recovered from IT(I, J) with an error of less than 100 meters.

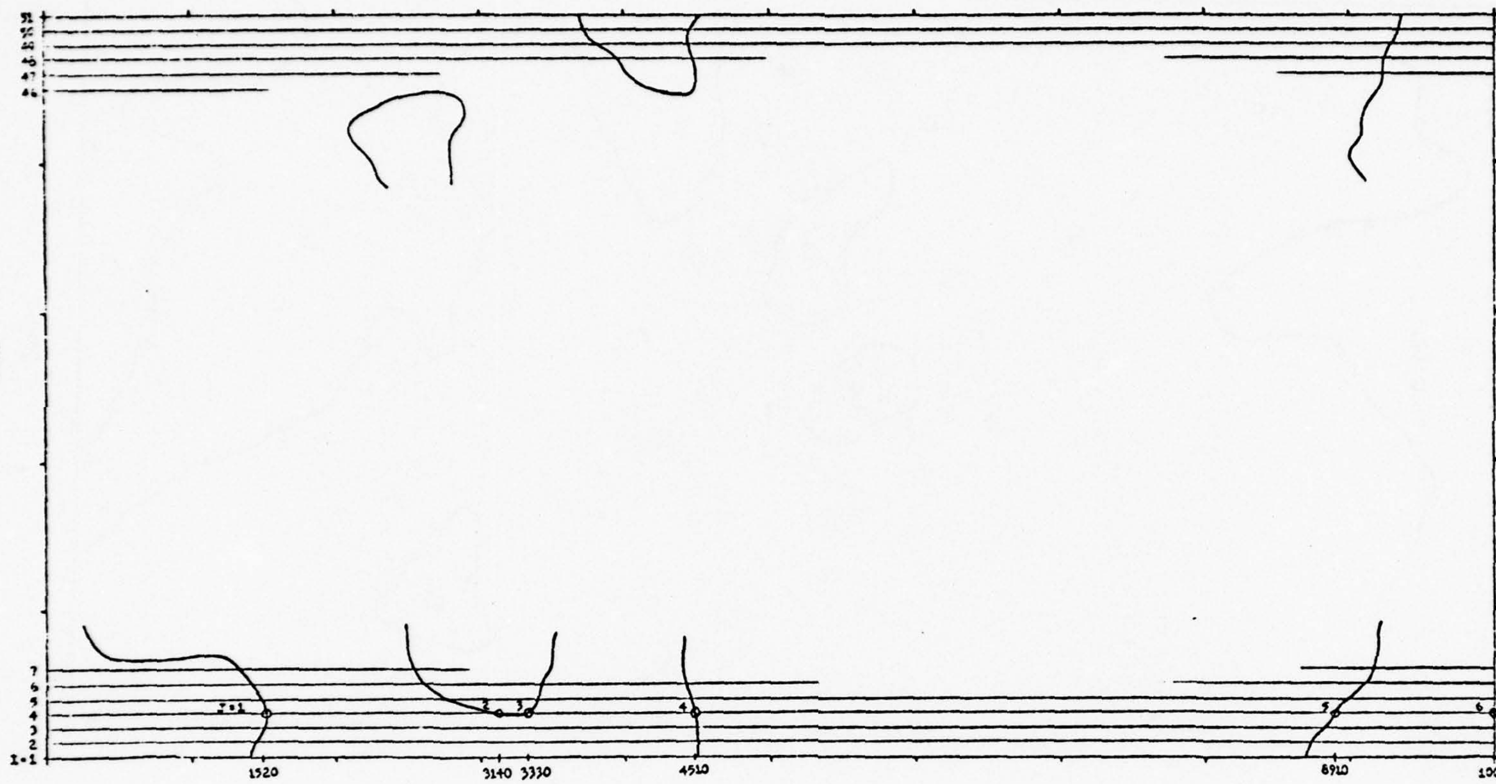
As an example of the procedure, suppose the 4^{th} strip boundary is being analyzed (Y = 300). From Figure A.5 it is seen that there are three forested intervals. The first occurs between X = 1520 and X = 3140, the second between X = 3330 and X = 4510, and the third between X = 8910 and X = 10000. Thus, the entries in IT for I = 4 are:

IT(4, 1) = 16	IT(4, 4) = 46
IT(4, 2) = 32	IT(4, 5) = 90
IT(4, 3) = 34	IT(4, 6) = 101



Original size of map: 7.5 x 14.5 inches

Figure A.4.--Forested Regions



Original size of map: 7. 5 x 14. 5 inches

Figure A. 5. --Representing Forested Regions

Note that if, for a given I, there are no forested intervals, then IT(I, 1) = 101 can be used to denote this fact.

Figure A.6 presents a plot of the forested regions as described by the method outlined above. The plot was prepared by computer and shows that the method results in a fairly accurate representation. The forst boundaries appear smooth and the shapes closely approximate those of the actual forested areas (see Figure A.4).

Now, to determine whether a given point (X, Y) lies within a forested region, the following procedure was used. First, the (X, Y) position is measured to the nearest 100 meters; that is

$$X' = \left[\frac{X + 50}{100}\right] \cdot 100$$

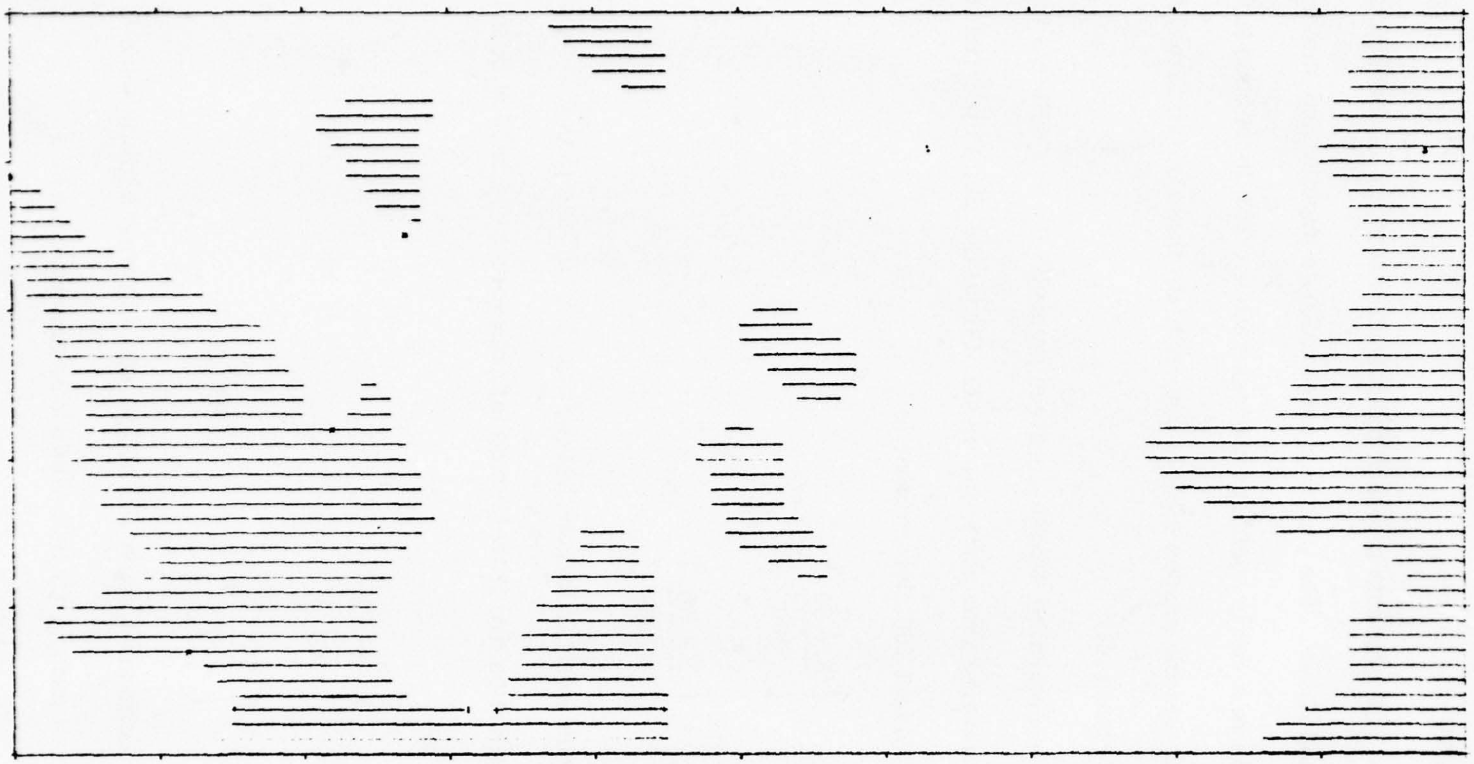
$$Y' = \left[\frac{Y + 50}{100}\right] \cdot 100$$

where $\left[A\right]$ indicates the largest integer equal to or less than A. Next, the modified coordinates are transformed into integers to be used with the matrix IT(I, J); that is

$$I' = \left[\frac{Y'}{100}\right] + 1$$

$$IT' = \left[\frac{X'}{100}\right] + 1$$

where $\left[A\right]$ is defined as above. Finally, the following logic is used to determine whether or not (X, Y) lies within a forested region:



Original size of map: 7.5 x 14.5 inches

Figure A. 6. --Computer Prepared Plot of Forested Regions

if $IT(I', 1) \leq IT' \leq IT(I', 2)$,

or $IT(I', 3) \leq IT' \leq IT(I', 4)$,

or $IT(I', 5) \leq IT' \leq IT(I', 6)$,

or $IT(I', 7) \leq IT' \leq IT(I', 8)$,

then (Y, Y) is in a forest; otherwise (X, Y) is not in a forest.

Using the above procedure the point (X = 8860, Y = 340) would be considered in a forest while the point (X = 8840, Y = 340) would not be. However, examination of Figure A.4 reveals that both points are in actuality outside the forest boundaries. Nevertheless errors of this magnitude were considered acceptable.

LOS Maps for Phase II Experiment

The Phase II Experiment described in Chapter 4 and Appendix D required that four unique tactical situations be developed, with each situation involving two enemy weapons located at separate positions on the battlefield. Analysis of the terrain revealed that the four situations could be represented satisfactorily by using only a total of five separate weapon positions. The five positions selected are outlined in Table A.1.

Table A.1

Weapon Positions

Weapon Position Number	X Coordinate	Y Coordinate
1	2630	1010
2	3600	1220
3	8070	2300
4	8640	2500
5	8770	4440

The four tactical situations were developed by forming pairs from the five weapon positions as indicated in Table A. 2. By comparing the terrain map in Figure A. 2 with the situations indicated in Table A. 2, it may be verified that each situation is representative of one that might be found in combat. All positions are seen to occupy key terrain. Furthermore, in each situation the two weapon positions are mutually supportive. That is, each weapon position could, if required, provide covering fire for the other position.

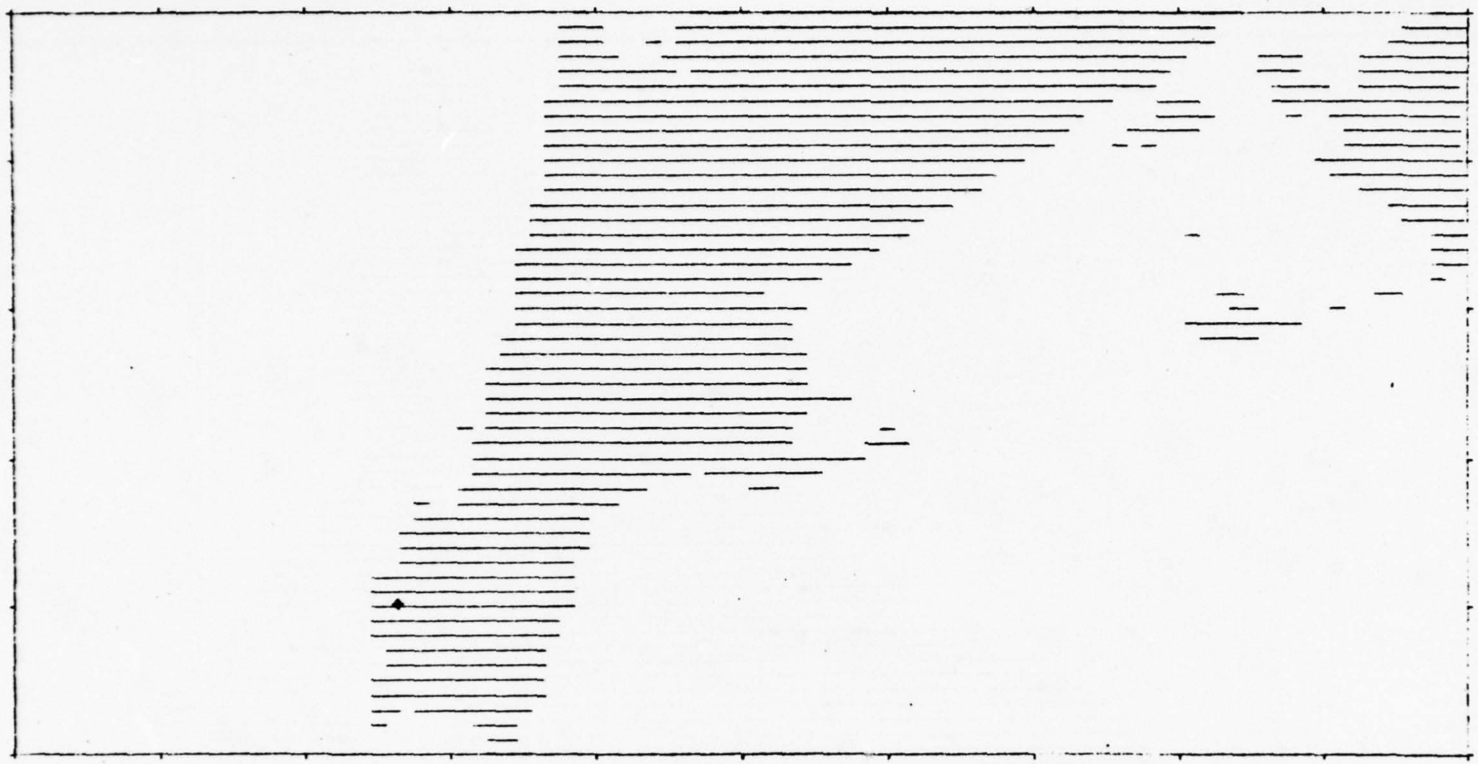
Now, LOS maps were required to depict intervisibility relationships for each of the four tactical situations. Of course, this meant that the LOS maps to be developed would actually be composite maps formed by overlaying the two maps associated with the two weapon positions considered in each tactical situation. Thus, five individual LOS maps corresponding to the five weapon positions of Table A. 1 were required. The maps appear in Figures A. 7 through A. 11, with shaded areas indicating intervisibility.

Figures A. 7 through A. 11 were prepared with the aid of a computer program developed specifically for the task. As a start point for the program, one

Table A. 2

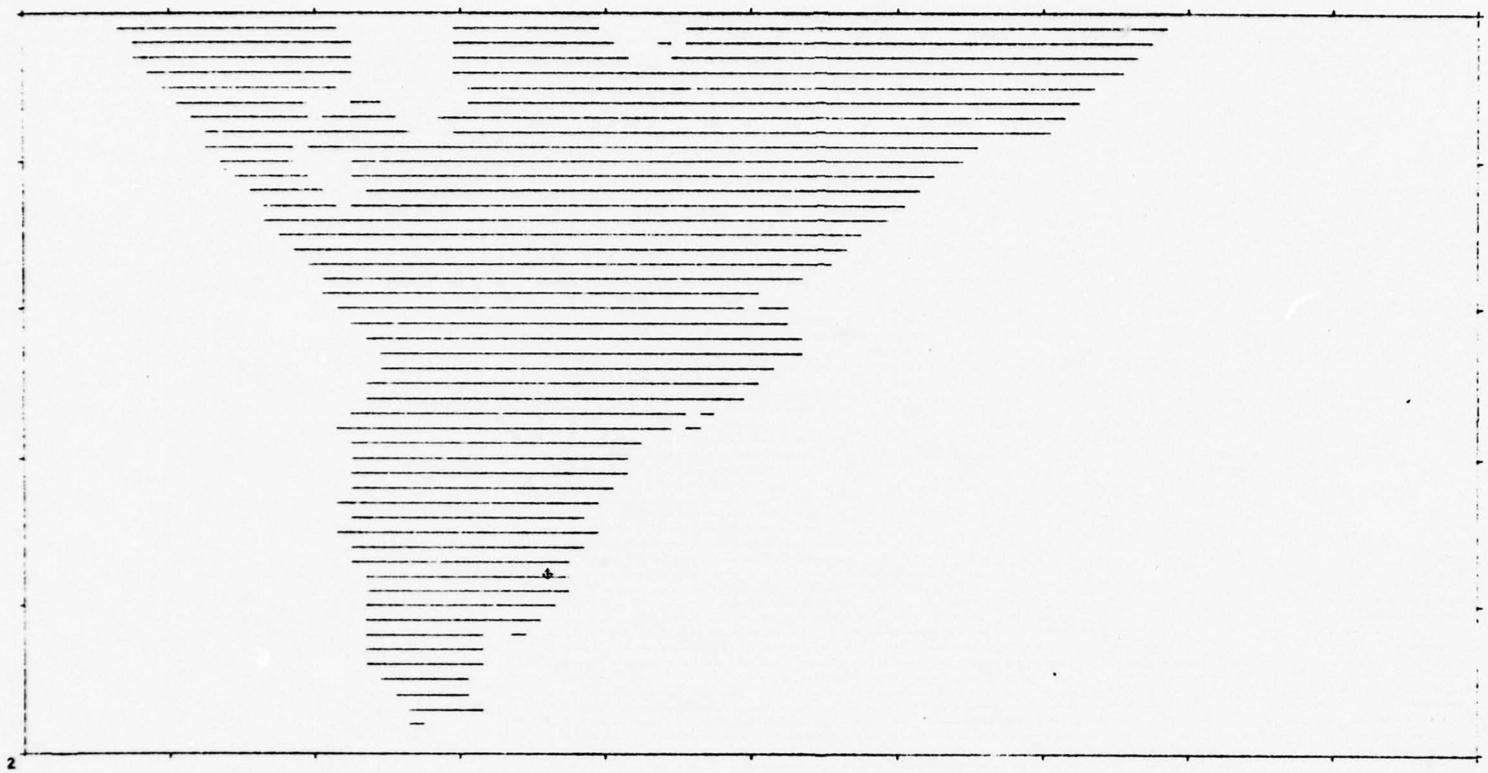
Tactical Situation Summary

Tactical Situation	Weapon Position Number	
	Weapon 1	Weapon 2
A	1	2
B	4	3
C	3	5
D	4	5



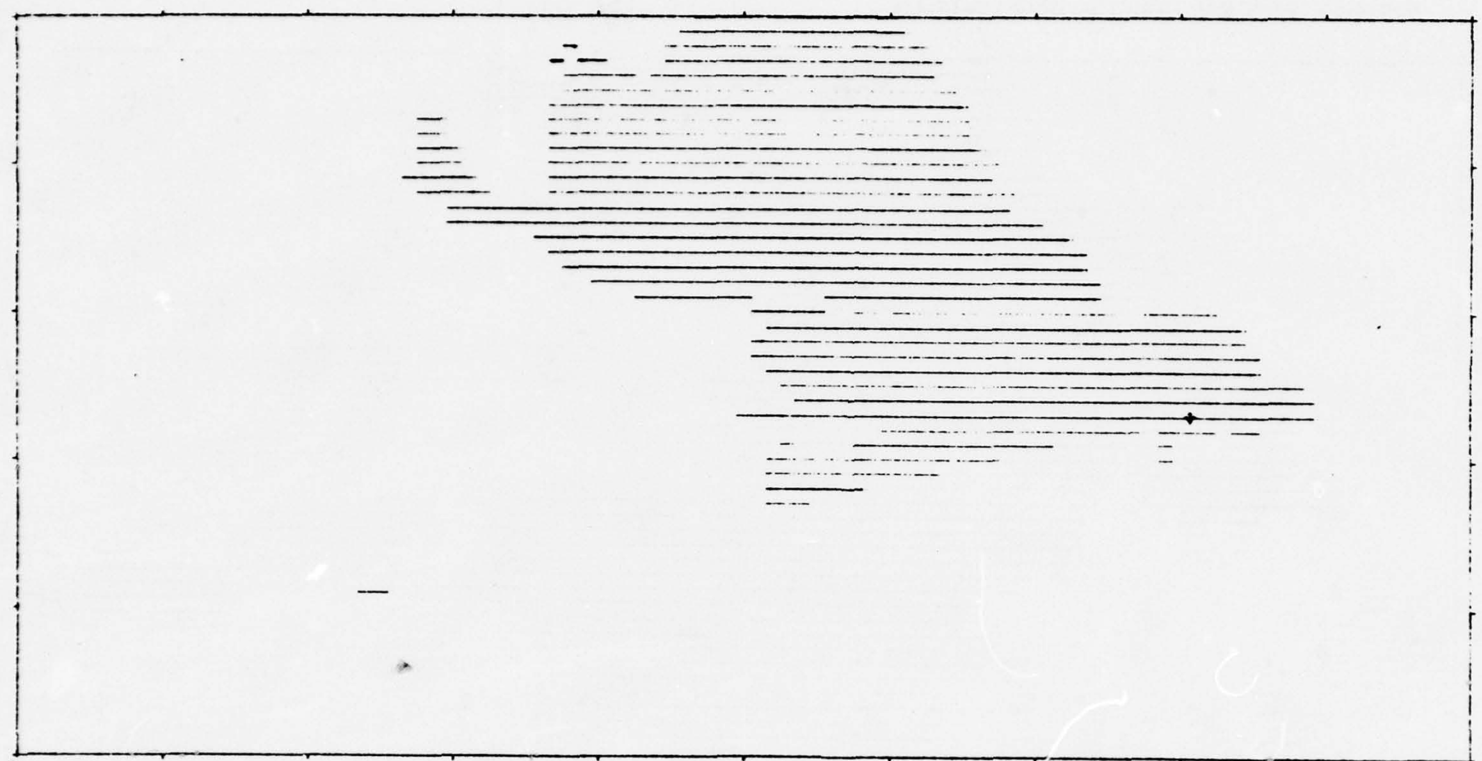
Original size of map: 7.5 x 14.5 inches

Figure A. 7. --LOS Map for Weapon Position 1



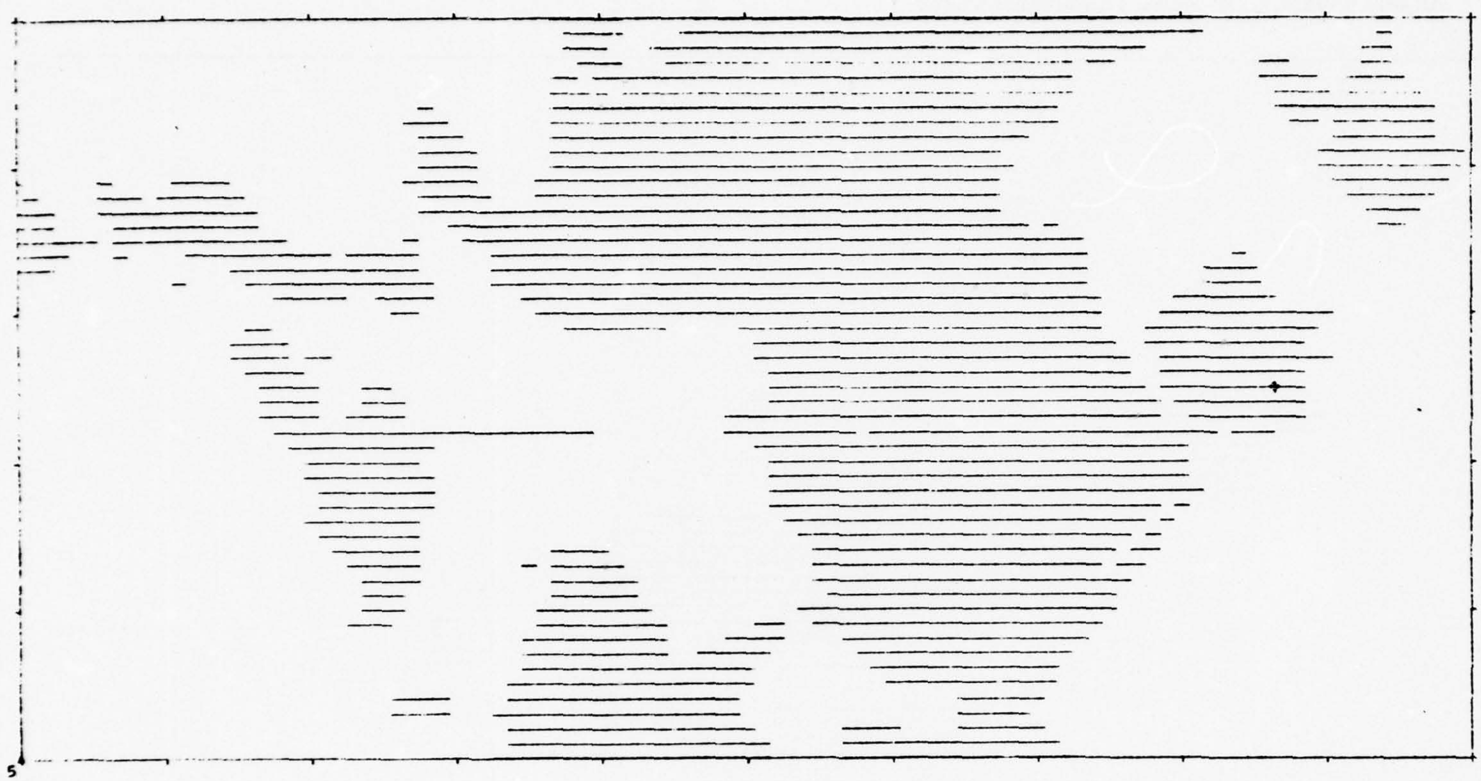
Original size of map: 7.5 x 14.5 inches

Figure A. 8. --LOS Map for Weapon Position 2



Original size of map: 7.5 x 14.5 inches

Figure A.9.--LOS Map for Weapon Position 3



Original size of map: 7.5 x 14.5 inches

Figure A.10.--LOS Map for Weapon Position 4

Original size of map: 7.5 x 14.5 inches

Figure A. 11. --LOS Map for Weapon Position 5

of the weapon positions specified in Table A. 1 is taken as the point (XT, YT) for which the LOS map is desired. Next, the elevation of the terrain ZT at (XT, YT) is found by interpolating (see Figure A. 3) upon the terrain data described earlier, and the height of the observer HLOS is determined using equation A. 1. Then, a uniform grid of points is laid down over the battlefield with each point separated from its neighbors by 100 meters. Each grid point (XO, YO) is then analyzed to determine if a LOS exists to the point (XT, YT, HLOS). This procedure consists first of an interpolation to find the terrain elevation ZO. Then the procedure outlined earlier is applied to determine whether (XO, YO) lies within a forest. Next, the appropriate altitude of the knap of the earth flight profile HFP is determined using equation A. 2. Finally, an algorithm developed by Clark (1969a) is used to determine whether or not the point (XT, YT, HLOS) is intervisible with the point (XO, YO, HLOS). The algorithm uses the planar representation (Figure A. 3) of the terrain elevation data to determine whether terrain (or woods) intersects a line between the two points.

Once each grid point has been analyzed for intervisibility, data for construction of the LOS map are available. Special library programs are used to generate an instruction deck, which in turn may be used to drive a plotter. The plotter then prepares a drawing of the type illustrated by Figures A. 7 through A. 11.

APPENDIX B

PHASE I EXPERIMENTAL MEDIA

Exhibit B.1

Experimental Session Plan

Part A Preliminary Session to Enlist Volunteers

A.1 Present discussion of general intent of the experiment

A.2 Pass out Volunteer Information Forms (VIF)

A.3 Collect completed VIF from each prospective subject

Part B Phase I Data Collection Session

B.1 Present introduction and scenario description

B.2 Pass out Enemy Weapon Brochure (EWB)

B.3 Present discussion of EWB

B.4 Pass out Master Information Form (MIF)

B.5 Present instructions for answering MIF questions I, II and III

B.6 Pause to permit subjects to answer MIF questions I, II and III

B.7 Present introduction to exposed threat evaluation subsession

B.8 Pass out Maximum Threat Assessment Form (MTAF)

B.9 Present instructions for using MTAF to locate maximum threat situation(s)

B.10 Present instructions for using prepunched computer data cards to record exposed threat values

B.11.a Present exposed threat assessment slides

B.11.b Pause on each slide to permit subjects to record answer

B.12.a Present instructions for using MTAF to record maximum threatening ranges

B.12.b Present example slide

B.13 Pause to permit subjects to record maximum threatening ranges

B.14 Present instructions for determining unexposed threat equivalent data

B.15.a Present unexposed threat equivalent slides

B.15.b Pause on each slide to permit subjects to record answer

B.16.a Present instructions for answering MIF question IV

B.16.b Present example slide

B.17 Pause to permit subjects to record answer

B.18 Collect all material from each subject

Exhibit B.2

Summary Text of Session Plan Item A.1

Intent of Experiment

The Ohio State University Systems Research Group (SRG) has been contracting almost continuously with the U. S. Army Combat Developments Command since 1950. This association commenced with studies of armored warfare conducted for the Armor Agency at Fort Knox, and more recently, has been carried on by contracts with the Systems Analysis Group at Fort Belvior. Contract work of a similar nature has also been performed for the U. S. Army Missile Command since 1966.

In 1965, SRG commenced work to build a simulation model of armored combat that has become known as DYNTACS. This model is designed to permit studies of the operational performance of armored units in attack, defense and delaying engagements. Therefore, DYNTACS takes into consideration many of the interactions that exist between the physical performance of weapons, the terrain and environment in which they operate, and the tactics with which they are employed.

DYNTACS is run on a large-scale digital computer in a completely "hands-off" mode. Thus, the various combat decisions made by individual tank commanders and by unit commanders must be modeled explicitly and internal to DYNTACS. Examples of such decisions are as follows:

At whom should a tank crew fire?
When should fire take place?
What ammunition should be used?
What route to the objective should the attacking unit choose?

These decisions models are supported with emperical data whenever possible.

In 1970, a very detailed model of helicopter operations was incorporated into DYNTACS for the Systems Analysis Group at Fort Belvoir. This model is designed to represent combat activities of helicopter units providing direct aerial fire support for tank units participating in the ground engagement. Therefore, the helicopter units operate in the conventional warfare environment implied by the types of engagements represented in DYNTACS. The model must predict operational performance of helicopter units with the same degree of accuracy as that which is produced by the model of ground unit performance. Thus, the interactions that exist between helicopter weapon performance, terrain over which the helicopter units operate, and the tactics with which they are employed, must be predicted accurately.

However, at the time the helicopter operations model was designed, detailed descriptions of helicopter tactics to be used in a conventional warfare environment were not available. Gross approximations were derived from stated doctrine and incorporated into the tactical decision models. However, no explicit emperical evidence existed to support more detailed representations of helicopter tactics. For example, the route to be used by a unit attacking a hard, highly lethal weapon is determined by a fairly unsophisticated model that is based upon doctrine but is largely unsupported by actual data.

This brings us to the problem at hand. SRG now intends to refine some of the existing helicopter tactical decision models by gathering experimental evidence from qualified Army aviators and by making model modifications as required. Therefore, SRG is seeking as many aviator volunteers as possible to participate in an experiment to be held here at Fort Rucker tomorrow (December 28, 1971). This experiment will be conducted in a classroom or other suitable indoor location to be announced, it will be strictly a pencil and paper exercise, and it will last approximately two hours. During the experiment volunteer subjects will be asked to make simple value judgments and to select routes in various hypothetical situations. The piloting skill of volunteer aviator subjects will never be in question; only their opinions as qualified military decision makers will be solicited. In fact, during the experiment and afterward, subjects will never be identified individually. All data collected will be handled with strictest confidence.

Please fill out the Volunteer Information Forms I am passing around now. If you wish to volunteer simply indicate your desire on the form and remain seated for further instructions. Others electing not to volunteer should fill out the form and hand it to me before leaving. I appreciate your cooperation and thank you on behalf of the Systems Analysis Group whose support makes this study possible.

Exhibit B. 3

Example of Session Plan Item A. 2

Volunteer Information Form

PLEASE COMPLETE ALL ANSWERS ON THIS FORM

I. **Personal Data:**

A. **Name** ______________________________ B. **Rank** ____________________
Last **First** **Middle**

C. **Date of birth** ______________________
Month **Year**

D. **Active service** ______________________
Years/Months

E. **Number of months at present duty station** ___________

II. **Total Rotary Wing Experience:**

A. **Approximate total flight time** ___________
Hours

B. **Approximate flight time in a combat zone** __________
Hours

1. **Location of combat zone** ______________________________
2. **Approximate dates in combat zone** ______________________
Month/Year

III. **Rotary Wing Combat Experience:**

A. **Approximate flight time (hours)**

1. **Gunship** ______________________
2. **Troop carrier** ______________________
3. **Observation** ______________________
4. **Med evac** ______________________
5. **Other (specify)** ______________________

B. Vehicle types (Huey, Cobra, etc.)

1. Gunship ____________________
2. Troop carrier ____________________
3. Observation ____________________
4. Med evac ____________________
5. Other (specify) ____________________

C. What is the most potent air defense weapon you have ever encountered? ____________________

Were you engaged? ____________________

Did you engage? ____________________

D. What types of weapons have you fired in combat?

Rockets ____________ Grenades ____________

7.62 mm ____________ Missiles ____________

Other (specify) ____________________

E. Have you ever engaged a tank or other hard, point target in combat? ____________________

If yes what types of weapons were used? ____________________

IV. Miscellaneous (IMPORTANT):

A. Have you ever been instructed, formally or otherwise, in the tactics and doctrine of helicopter employment in conventional, mid-intensity warfare? ____________________

If yes, please describe the circumstances.

V. Availability:

Do you volunteer to participate in the described experiment (of approximately two hours duration) ____________________

____

Exhibit B.4

Summary Text of Session Plan Item B. 1

Introduction and Scenario Description

Good morning gentlemen. As indicated yesterday we are going to be together for about two hours today, and during this time we are going to be concentrating on the mental process by which you select routes in combat.

You have been selected to participate because each one of you has faced the enemy in combat and has experienced the problem of selecting a route to be followed while attacking a target. Let me emphasize again that there are no right or wrong answers to any of the questions that I will ask you this morning. Your skill as an aviator is not in question. Instead, I wish only to obtain your opinions as highly qualified military decision makers. The data that I collect will be held in strictest confidence.

Now, to give us a frame of reference, let me describe a tactical scenario that gives rise to the type of route selection task in which I am interested in this experiment. This scenario is typical of one which you might actually experience in a mid-intensity conventional warfare environment. Also, it is the scenario that you should have in mind each time you feel a need to relate to the "real world" in order to answer any of the questions which I will ask you later on during the session.

Consider a fire team of Army attack helicopters whose mission it is to provide immediate direct aerial fire support to an armored battalion in a mid-

intensity conventional warfare situation. The battalion has been fighting a delaying engagement and has fallen back through a succession of defensive positions over a period of several days. The fire team has assisted in the delay by providing harassing fires in the enemy flanks and by serving as part of the base of fire used to cover each withdrawal. The enemy has occupied and consolidated his hold on each position prior to initiating the attack on additional objectives.

Now, the friendly forces have begun to contain the attack and the first major thrust to recapture lost territory is to be mounted. As the battalion commences its assault the enemy is able to bring elements of the maneuver force under very heavy fire and before long an entire company is pinned down. The battalion commander is faced with the alternatives of diverting part of his force to attack the enemy position from its flank or of requesting some form of fire support to neutralize or destroy the enemy position. He decides to utilize the attack helicopter team.

The helicopter team has been waiting in anticipation of just such a mission. It has been sitting on the ground to the immediate rear of the supported battalion and is fully armed and fueled. The team consists of two advanced fire support helicopters with point fire missiles as their primary anti-armor armament.

By radio, the battalion commander gives the team leader a description of the target and a briefing regarding the disposition of friendly forces and the suspected locations of other hostile forces. The mission for the helicopter team is to destroy the enemy position that is impeding the conduct of the attack.

As described, the enemy position is occupied by two tanks, an armored personnel carrier and a self propelled anti-aircraft gun. The APC serves as the transport vehicle for two dismounted crews, each equipped with a medium anti-tank weapon. The anti-aircraft gun provides defense for the position from aerial attack.

In addition to the weapons at the target position there is a reported enemy anti-aircraft gun located to the rear of the target position but close enough to provide supporting fire against any helicopters that might attack. This weapon is radar directed and provides a large volume of highly lethal fire.

Upon receipt of the mission request the fire team leader marks the positions of the target and the supporting anti-aircraft gun on his map. He then commences preparation of a plan of attack for his fire team. He must select a route to the vicinity of the target and a return route to be used upon completion of the mission. He must also select the method by which the target will be attacked. The entire attack plan is recorded on the map and is conveyed to the other team member prior to take-off.

Now, the attack plan serves only as a guide during the mission. Obviously, as the situation unfolds, as the enemy takes action, as the terrain actually becomes visible, as ordnance is delivered, the plan will change. The team leader must make decisions during the entire mission that affect the outcome of the mission. However, a very important part of the mission is the

initial plan and it is this planning operation that I have referred to earlier as the route selection process.

During the experiment, details of the missions you are asked to visualize will change. That is, the type of enemy weapon to be attacked and the type of emeny weapon in support of the target will not be the same as described above. However, the overall tactical situation and the route planning task you are given will always remain as outlined.

Exhibit B. 5

Example of Session Plan Item B. 2

Enemy Air Defense Weapons
(Unclassified--for illustrative purposes only)

I. General Description

The REDEYE is an all arms, man-portable, shoulder-launched, heat seeking guided missile system. Each launch team of two men is supplied with a basic load of six rounds.

The 23 mm quad self-propelled antiaircraft weapon is a light antiaircraft weapon system consisting of a radar-directed, quad-mount, 23 mm automatic weapon mounted on a fully-tracked chassis. The weapon is manned by a crew of four and is supplied with a basic load of 4000 rounds.

The 14.5 mm quad antiaircraft weapon is a light antiaircraft weapon system consisting of a quad-mount, 14.5 mm automatic weapon with ring sight mounted on a fully-tracked armored personnel carrier. The weapon is manned by a crew of three and is supplied with a basic load of 8000 rounds.

II. Performance Characteristics

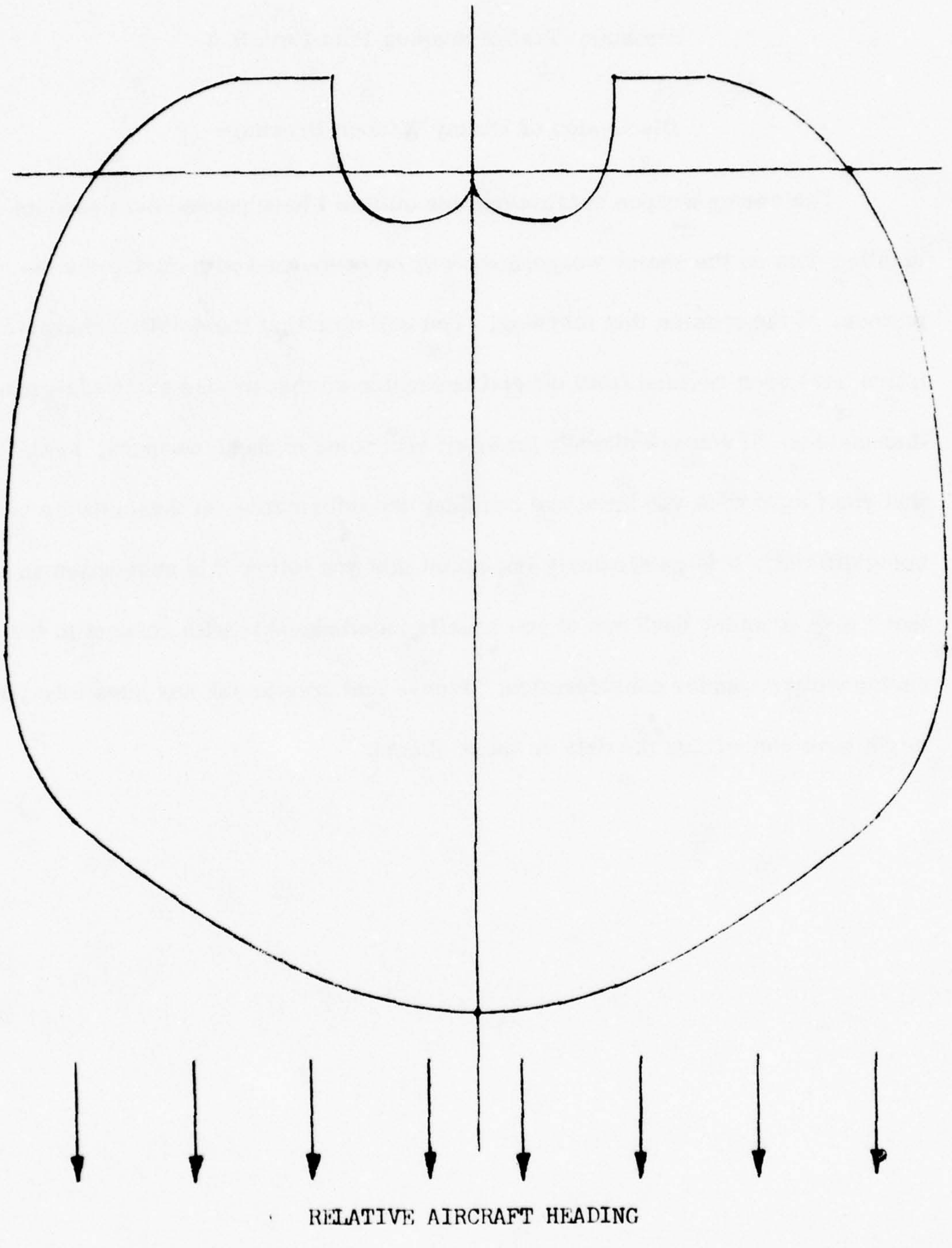
Weapon	Effective Range		Practical Rates of Fire (rd/min)	Time to fire first round	Projectile
	Minimum (M)	Maximum (M)			
REDEYE	See launch envelope	See launch envelope	3	10	A
23 mm	100	3000	275	8	B
14.5 mm	100	1400	600	8	C

Projectile	Weight (lb)	Type	Fuzing
A	3.0	HEI	Impact
B	1.0	API HEI	Impact
C	0.3	API	Impact

API - Armor piercing incendiary

HEI - High explosive incendiary

REDEYE



LAUNCH PERFORMANCE ENVELOPE
(Unclassified--for illustrative purposes only)

Exhibit B. 6

Summary Text of Session Plan Item B. 3

Discussion of Enemy Weapon Brochure

The enemy weapon characteristics outline I have passed out presents detailed data on the enemy weapons we will be concerned with during the remainder of the session this morning. You will note that the detailed characteristics have been revised from official estimates so that we can avoid classified discussions. If you are already familiar with some of these weapons, I ask that you forget what you know and consider the information on these sheets as being official. It is particularly important that you follow this suggestion so that I may consider each one of you equally knowledgeable with respect to the enemy weapons under consideration. Please feel free to ask any questions you might have concerning the data on these sheets.

Exhibit B. 7

Example of Session Plan Item B. 4

MASTER INFORMATION FORM

I. Subject Number __________ Subject Name ______________________________

Last First

II. Vehicle Type * ________________

III. Speed Information

A. During knap of the earth flight to a firing position

1. Average speed (knots) ________________

2. Range of variation (± knots) __________

3. Additional comments

B. During firing run

1. Average speed (knots) ________________

2. Range of variation (± knots) __________

3. Describe the manner in which speed changes during various stages of a firing run.

4. Additional comments

*Record the vehicle type in which you would feel most comfortable were you to be faced with a mission of the type described in the introduction.

IV. Enemy Weapon Rating

Rank	Weapon
1	______
2	______
3	______
4	______

100

50

0

IV. Route Rating

Rank	Route
1	______
2	______
3	______
4	______

100

50

0

VI. Preferred Mailing Address and Phone Number

____

____

____

Exhibit B. 8

Summary Text of Session Plan Item B. 7

Introduction to Exposed Threat Evaluation

Gentlemen, during the remainder of the session we are going to be discussing your feelings about the enemy weapons that were described to you earlier. In particular, we are going to discuss the "threat" you would feel were you to be exposed to the weapons under various tactical conditions. This is the reason we spent a considerable amount of time in becoming familiar with the weapons.

Now, what do we mean by "threat." Suppose you were flying at tree top level and you suddenly realized that for the next fifteen (15) seconds you were going to be exposed to an enemy 23 mm weapon. Furthermore, suppose you knew that the bearing from your helicopter to this weapon would be ninety (90) degrees and the range would be one-thousand (1000) meters. The "threat" we are interested in is that feeling in the pit of your stomach you would have when you first realized the experience you were about to endure. I believe this feeling is commonly referred to as "pucker factor" among military men for reasons we need not pursue.

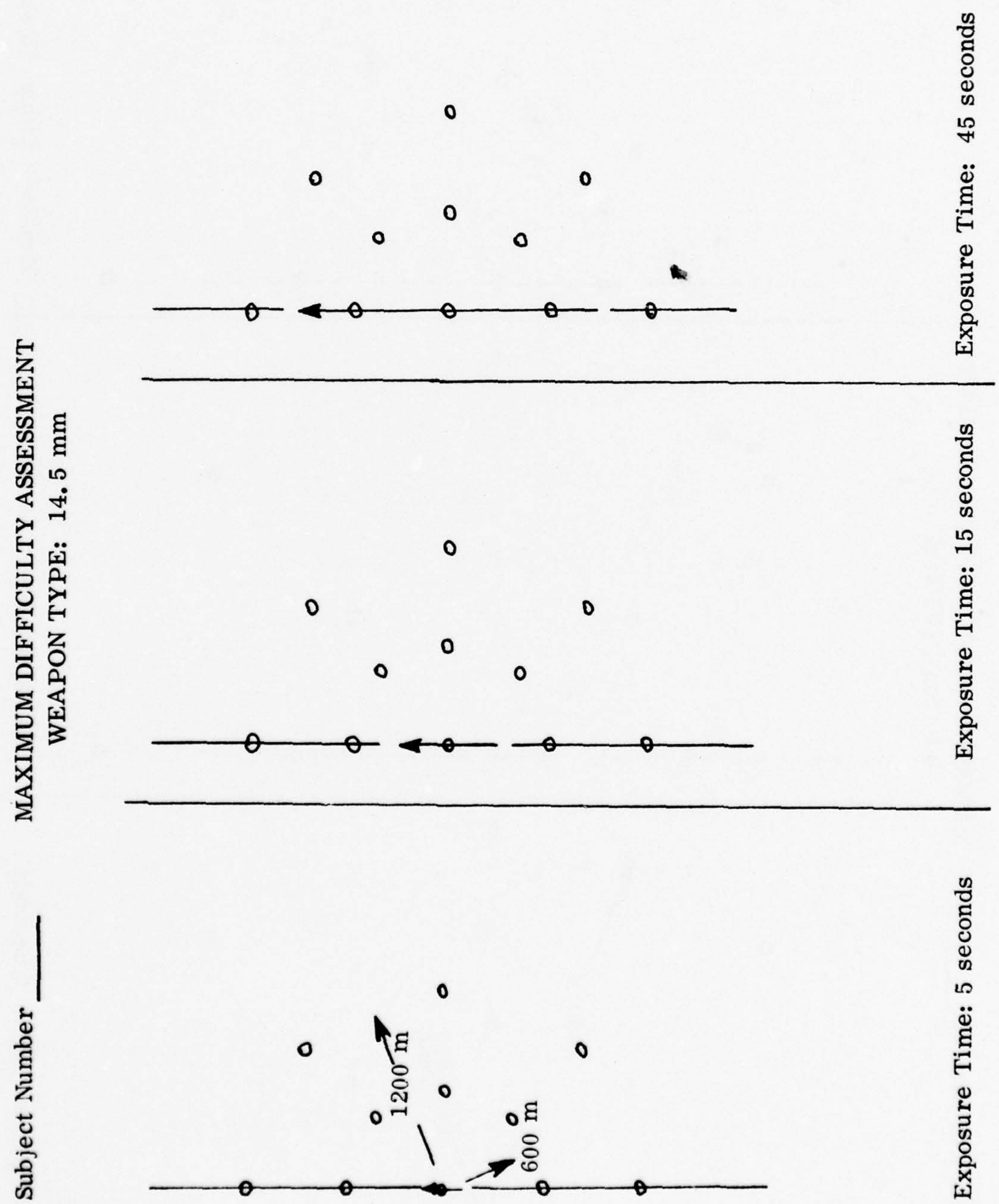
Presumably, we could change any of the situation variables in the example outlined above and your feeling of threat would also change. For example, the exposure time could go up or down, the type of enemy weapon could change, or the relative bearing and range to the weapon could be altered. For each combination of these variables you might register a different feeling of threat.

In the remainder of this session we are going to examine a variety of exposure situations involving the enemy weapons discussed earlier. Using a method to be explained, you will actually attach numbers to the threat you feel in each situation and in this way I will obtain part of the data required in my study of the route selection process.

Let me stress again that in registering your feelings about threat you should try to use as a frame of reference the weapon characteristics that have been outlined for you today. Please try to refrain from interjecting your own private knowledge of the enemy weapons. We wish to have everyone working from the same information base in this experiment.

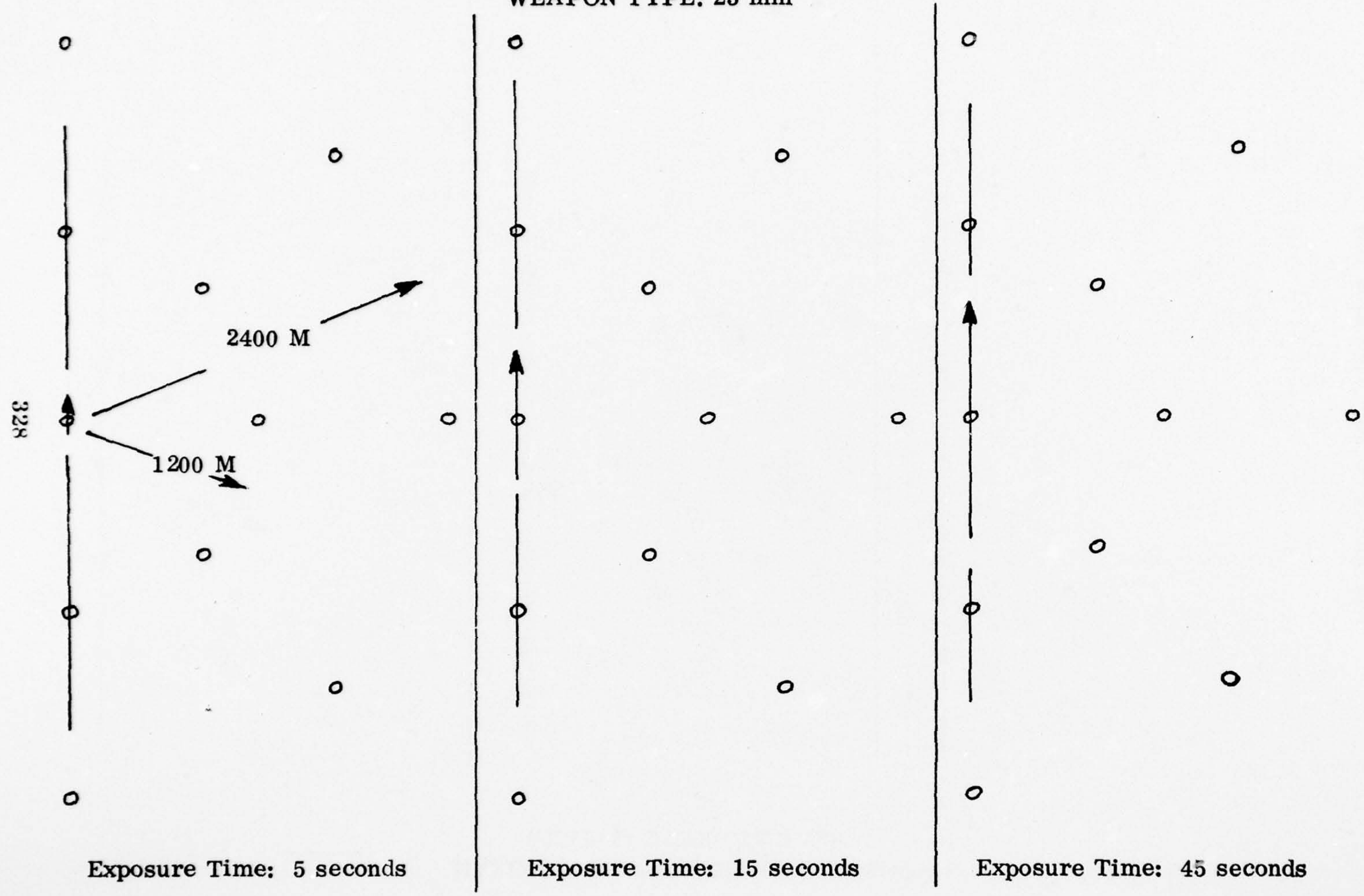
Exhibit B. 9

Example of Session Plan Item B. 8



Subject Number ____

MAXIMUM DIFFICULTY ASSESSMENT
WEAPON TYPE: 23 mm



Subject Number ______

MAXIMUM DIFFICULTY ASSESSMENT
WEAPON TYPE: REDEYE

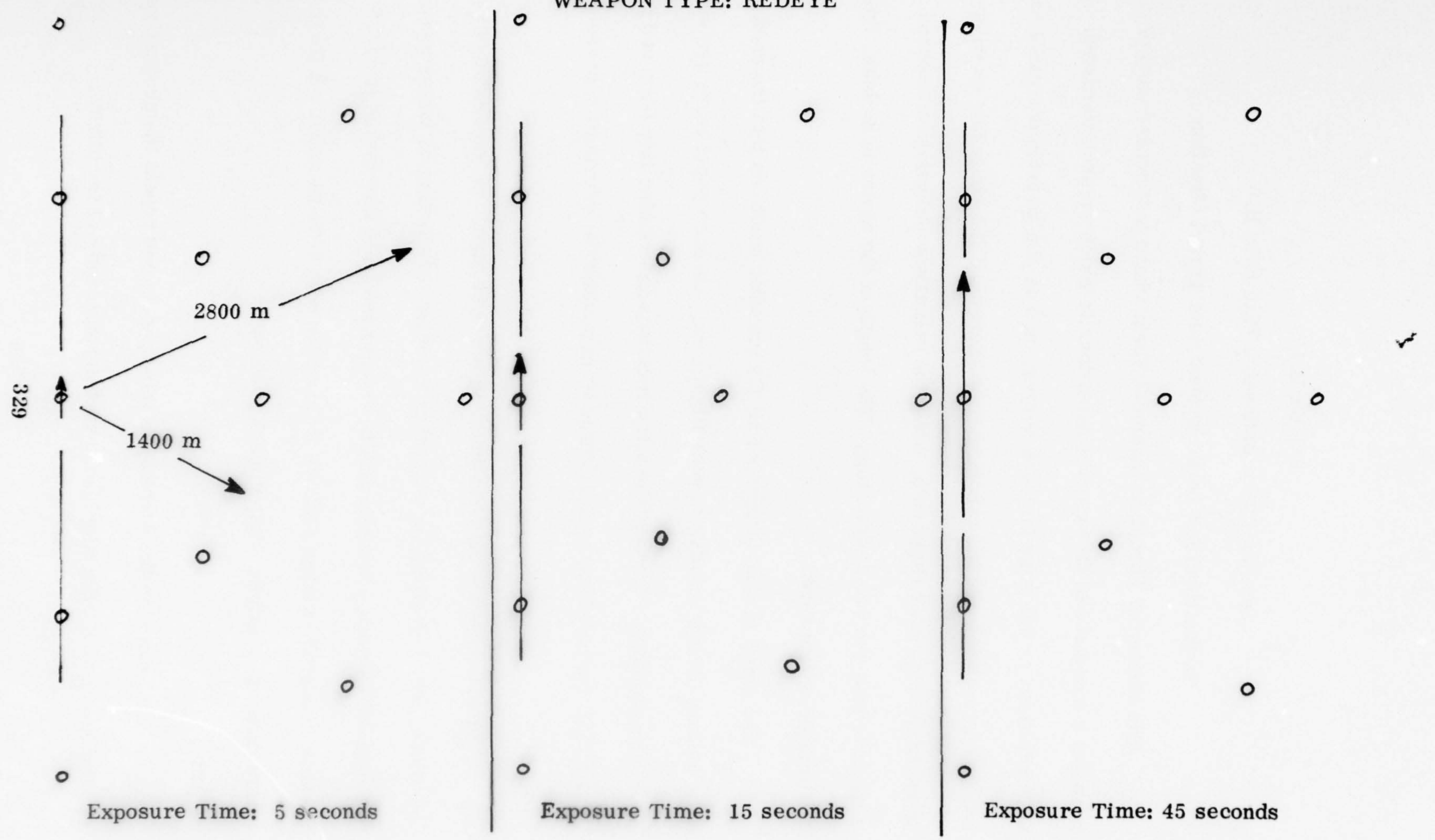


Exhibit B.10

Summary Text of Session Plan Item B.9

Instructions for Locating Maximum Threat Situation

The Maximum Threat Assessment Form I have just handed each of you presents a summary of all exposure situations in which we are interested. You will note there is one page for each weapon, and as you go from one panel to another on a given page the exposure time changes. The black line on each panel represents your flight path, while the red arrow indicates an exposed segment which you are anticipating. The length of the arrow is a visual clue to the amount of exposure.

The small circles represent all the possible positions that the enemy weapon may occupy relative to your flight path. On each panel there are eleven (11) such positions. Please take a few moments to examine this form and feel free to ask any questions you might have regarding the information presented.

(Pause)

Please examine the first panel on the first page. Of the eleven enemy positions, which position do you feel is the most threatening as far as you are concerned? That is, in which position would you least like to find the 14.5 mm weapon situated? Please indicate the position with a check mark. If there is more than one position, simply mark each one.

(Pause)

Now, examine the second and third panels and repeat the process you used on the first panel. Examine each panel independently of the others.

(Pause)

When you have finished the third panel, I want you to consider the checked positions on all three panels simultaneously. Of the positions checked which one(s) is the most threatening? Please indicate your selection(s) with a circle around the check mark(s).

(Pause)

Now repeat the above process for the second page, and when you finish, proceed to the third page. Consider each page independently of the other two.

(Pause)

Finally, I want you to examine the circled check marks and determine that position(s) which is the most threatening. That is, in this last step we are locating the position(s) that is the most threatening of all ninety-nine (99) positions. Place a square around the position selected.

(Pause)

Now, what we have determined is the most threatening enemy position of all positions that we will examine today. Let us now agree that when we encounter this situation in the upcoming presentation of exposure situations, we will assign a value of one-thousand (1000) to the situation that we feel most threatening. Let us further agree that if we feel no threat whatsoever in a given situation we will assign a value of zero to the threat (0). Thus, all situations will be assigned a threat value that lies between zero (0) and one thousand (1000). Please write these numbers down on the form as a reference, and keep this form handy during the remainder of the session.

Exhibit B. 11

Summary Text of Session Plan Item B. 10

Instructions for Using Data Cards

Now that we have defined threat and have developed a method to record threat as a numerical quantity, we are going to put the method to use by showing a series of slides depicting various exposure situations. As each slide is presented you will record the threat you feel according to the method that we have developed.

Your answers are to be placed on the computer data cards that each of you have in your supply box. You will notice that the card deck consists of one hundred eighteen (118) cards and that all the cards have your SUBJECT NUMBER recorded on them. The cards are ordered by the SLIDE NUMBER appearing at the center of each card. These numbers correspond to the numbers of the slides that I am going to present to you.

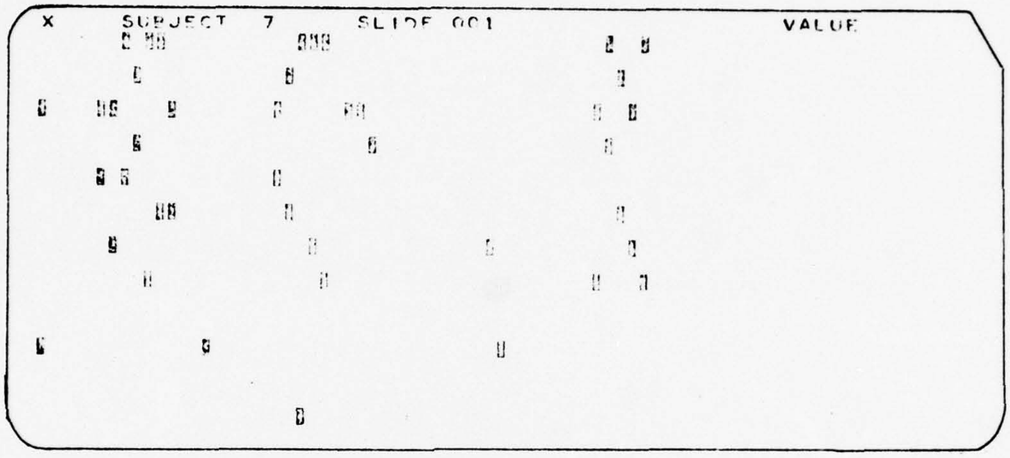
As each slide is presented, you will check the slide number on the screen against the slide number on the card. Then, after studying the situation depicted by the slide, you will record the threat you feel on the card. Your answer should appear in the clear area of the card under the word VALUE.

As each slide is shown I will allow ample time for you to analyze the situation and record your answer. As soon as you complete each card simply place it back in the supply box so that it cannot be referred to again.

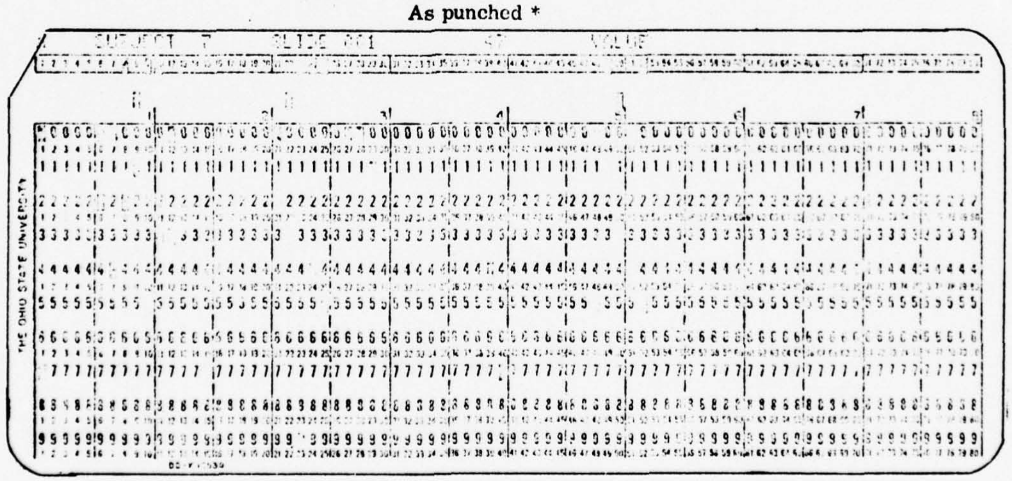
Exhibit B. 12

Example of Cards Used in Session Plan Item B. 11

As seen by subjects



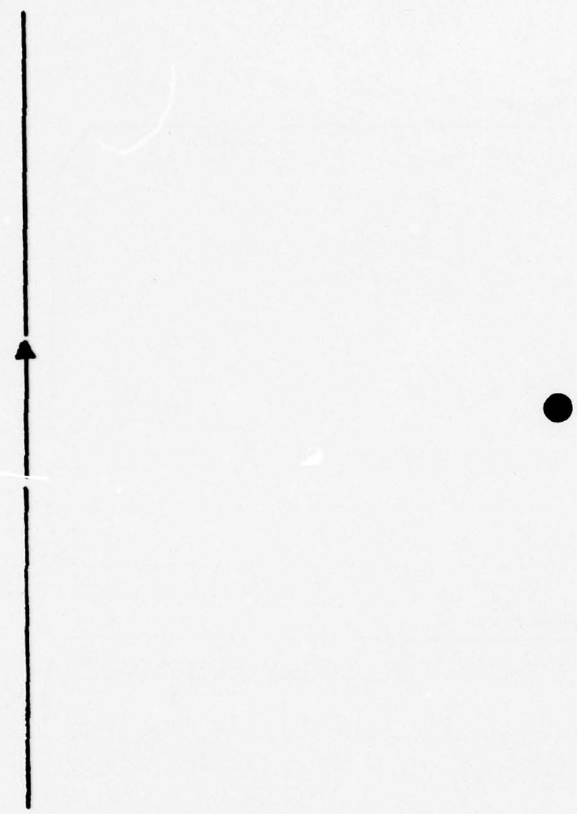
As punched *



* Situation Number - see Exhibit B. 14

Exhibit B. 13

Examples of Session Plan Item B. 11



WEAPON TYPE . . . . . . 23 mm

EXPOSURE TIME . . . . . 15 seconds

MINIMUM RANGE . . . . . 2400 m

MAXIMUM RANGE . . . . . 2420 m

1

WEAPON TYPE . . . . . . 14.5 mm

EXPOSURE TIME . . . . . 45 seconds

MINIMUM RANGE . . . . . 0 m

MAXIMUM RANGE . . . . . 1530 m

2

WEAPON TYPE . . . . . . 23 mm

EXPOSURE TIME . . . . . 5 seconds

MINIMUM RANGE . . . . . 2330 m

MAXIMUM RANGE . . . . . 2470 m

3

WEAPON TYPE . . . . . . REDEYE

EXPOSURE TIME . . . . . 15 seconds

MINIMUM RANGE . . . . . 0 m

MAXIMUM RANGE . . . . . 310 m

4

WEAPON TYPE ...... 14.5 mm

EXPOSURE TIME ..... 5 seconds

MINIMUM RANGE ..... 1100 m

MAXIMUM RANGE ..... 1300 m

5

Exhibit B. 14

Definition of Situations Presented in
Session Plan Item B. 11

Weapons (W)	
Level (I)	Type
1	14. 5 mm
2	23 mm
3	REDEYE

Exposure Time (T)	
Level (J)	Value (seconds)
1	5
2	15
3	45

Weapon Level (I)	Range (R)	
	Level (K)	Value (meters)
1	1	1200
	2	600
	3	0
2	1	2400
	2	1200
	3	0
3	1	2800
	2	1400
	3	0

Relative Bearing (ϕ)	
Level (L)	Value (degrees)
1	0
2	45
3	90
4	135
5	180

Situation Number

$$N = 33\,(I-1) + 11\,(J-1) + 5\,(K-1) + L \quad \text{for } K = 1, 2$$

$$N = 33\,(I-1) + 11\,J \quad \text{for } K = 3$$

Exhibit B.15

Ordering of Situations Presented in Session Plan Item B.11

Slide	Situation	Levels				Slide	Situation	Levels			
		W	T	R	ϕ			W	T	R	ϕ
1	47	2	2	1	3	41	58	2	3	1	3
2	28	1	3	2	1	42	24	1	3	1	2
3	37	2	1	1	4	43	16	1	2	1	5
4	88	3	2	3	-	44	79	3	2	1	2
5	5	1	1	1	5	45	38	2	1	1	5
6	19	1	2	2	3	46	77	3	1	3	-
7	67	3	1	1	1	47	12	1	2	1	1
8	90	3	3	1	2	48	59	2	3	1	4
9	10	1	1	2	5	49	52	2	2	2	3
10	64	2	3	2	4	50	30	1	3	2	3
11	1	1	1	1	1	51	9	1	1	2	4
12	15	1	2	1	4	52	78	3	2	1	1
13	53	2	2	2	4	53	96	3	3	2	3
14	91	3	3	1	3	54	72	3	1	2	1
15	95	3	3	2	2	55	65	2	3	2	5
16	49	2	2	1	5	56	86	3	2	2	4
17	29	1	3	2	2	57	61	2	3	2	1
18	37	2	1	1	4	58	67	3	1	1	1
19	56	2	3	1	1	59	41	2	1	2	3
20	6	1	1	2	1	60	73	3	1	2	2
21	33	1	3	3	-	61	51	2	2	2	2
22	47	2	2	1	3	62	13	1	2	1	2
23	85	3	2	2	3	63	10	1	1	2	5
24	88	3	2	3	-	64	69	3	1	1	3
25	60	2	3	1	5	65	18	1	2	2	2
26	22	1	2	3	-	66	99	3	3	3	-
27	92	3	3	1	4	67	54	2	2	2	5
28	55	2	2	3	-	68	28	1	3	2	1
29	2	1	1	1	2	69	81	3	2	1	4
30	8	1	1	2	3	70	34	2	1	1	1
31	32	1	3	2	5	71	75	3	1	2	4
32	84	3	2	2	2	72	26	1	3	1	4
33	44	2	1	3	-	73	76	3	1	2	5
34	5	1	1	1	5	74	62	2	3	2	2
35	80	3	2	1	3	75	74	3	1	2	3
36	39	2	1	2	1	76	90	3	3	1	2
37	3	1	1	1	3	77	70	3	1	1	4
38	19	1	2	2	3	78	27	1	3	1	5
39	89	3	3	1	1	79	83	3	2	2	1
40	66	2	3	3	-	80	57	2	3	1	2

Slide	Situation	Levels			
		W	T	R	ϕ
81	82	3	2	1	5
82	31	1	3	2	4
83	7	1	1	2	2
84	17	1	2	2	1
85	45	2	2	1	1
86	68	3	1	1	2
87	94	3	3	2	1
88	14	1	2	1	3
89	36	2	1	1	3
90	46	2	2	1	2
91	64	2	3	2	4
92	50	2	2	2	1
93	21	1	2	2	5
94	93	3	3	1	5
95	11	1	1	3	-
96	48	2	2	1	4
97	97	3	3	2	4
98	4	1	1	1	4
99	63	2	3	2	3
100	87	3	2	2	5
101	42	2	1	2	4
102	25	1	3	1	3
103	20	1	2	2	4
104	35	2	1	1	2
105	71	3	1	1	5
106	40	2	1	2	2
107	23	1	3	1	1
108	98	3	3	2	5
109	43	2	1	2	5
110	74	3	1	2	3
111	19	1	2	2	3
112	63	2	3	2	3
113	8	1	1	2	3
114	96	3	3	2	3
115	52	2	2	2	3
116	30	1	3	2	3
117	85	3	2	2	3
118	41	2	1	2	3

Exhibit B. 16

Summary Text of Session Plan Item B. 12. a

Instructions for Maximum Threatening Range

During the portion of the experiment in which I asked for your evaluation of the 109 slides depicting exposure to enemy weapons, you responded with numbers between zero and one thousand (0 - 1000) to indicate the threat you felt in each situation. The maximum range between your line of flight (exposed) and the enemy weapon was approximately 80% of the stated maximum effective range. Presumably, you may have felt threatened even at these extreme ranges. The question becomes, for each type of weapon and for each enemy weapon bearing and exposure time, at what range do you no longer feel threatened by that weapon. That is, at what range would you feel free to enter a zero (0) to indicate the threat you feel.

Please retrieve the form you used earlier during the experiment to determine the situation you felt to be the most threatening of all situations to be presented. Record your answers on this form. As indicated by the example I am going to present on the screen, the range you record can change with bearing as well as with weapon type and exposure time. You should record a total of forty-five answers in all.

Exhibit B.17

Example of Session Plan Item B.12.b

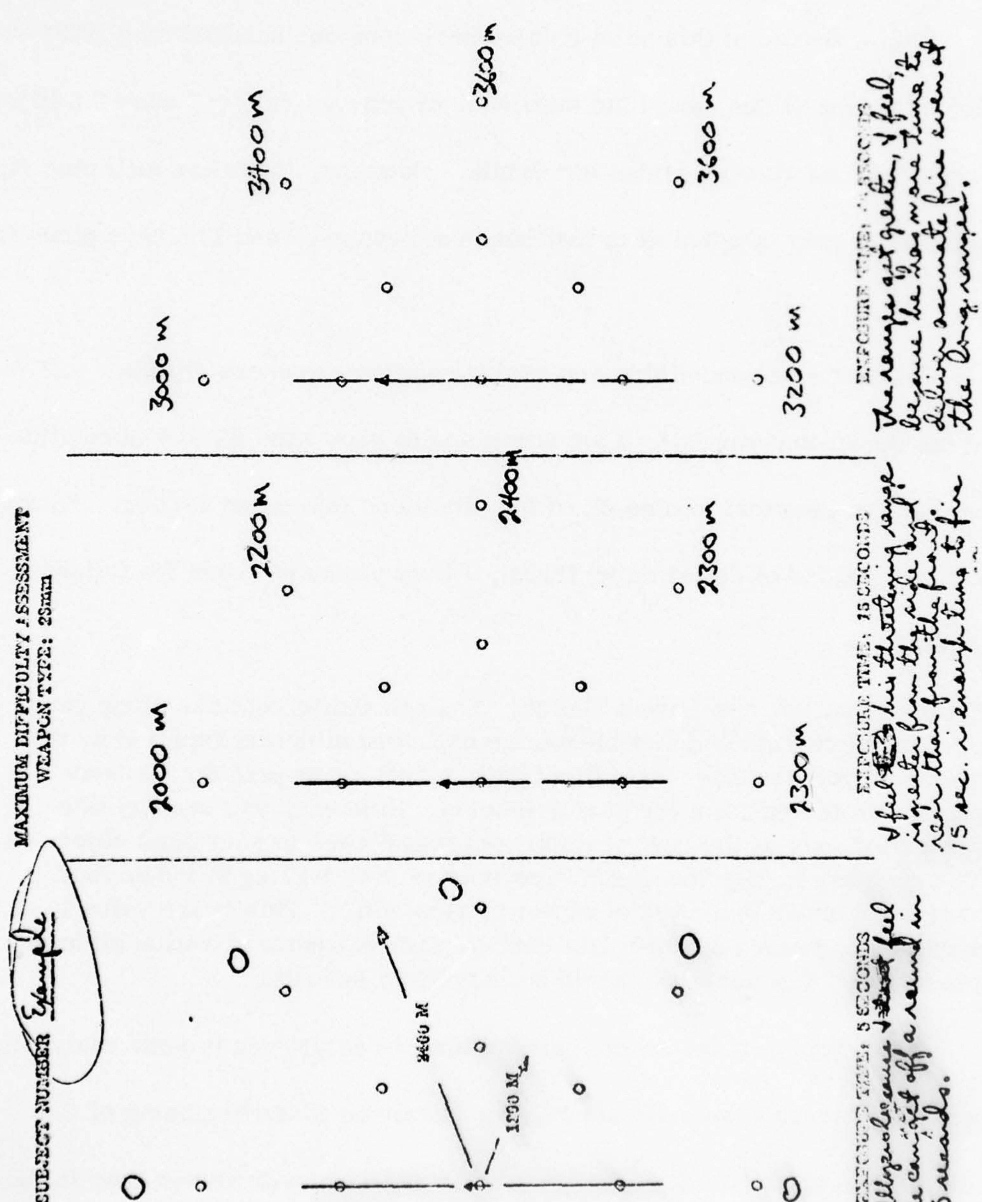


Exhibit B.18

Summary Text of Session Plan Item B.14

Instructions for Unexposed Threat Equivalent

You will note at this point that we have seen one hundred nine (109) exposure situation slides, and I am sure each of you was relieved when I told you we were finished viewing slides for awhile. However, there are still nine (9) data cards in your original deck that have not been used and I do have plans for them.

Earlier I requested that you analyze a given exposure situation and record the threat that you felt. I am now going to show nine (9) exposure situations that are identical to nine (9) of the situations presented earlier. However, this time, instead of determining threat, I want you to perform the following analysis:

> Suppose that you now have a choice. You can either continue along your present flight path and experience the exposure situation depicted by the slide, or you can alter your flight path to find a new path that is completely protected from the enemy weapon. However, you can buy this protection only at the cost of increased travel time to your final objective. The question is "By how much time would you be willing to delay your arrival in order to avoid the exposure situation?" This is the value I want you to record on each data card as each exposure situation slide is presented. The answers should be in units of seconds.

Now, let me make several suggestions to assist you in your analysis. First, please recall the scenario that we discussed at the beginning of this session. You should think of the tradeoff of exposure with travel time in the context of the mission that was described as part of the scenario description. Next, if you feel no threat in a particular situation then you should most

probably enter zero (0) seconds as your answer since you would not normally want to delay your arrival to avoid a nonthreatening situation. Finally, if you feel threatened in a given situation, you might start with a delay time large enough to insure that the exposure situation would be preferred to the delay. Then you might decrease the delay mentally until you have difficulty deciding whether exposure or delay is preferred. At this point you will have the delay time that should be entered as your answer.

Between each slide in the sequence that I am now going to present I will allow ample time for you to perform your analysis and record your answer.

Exhibit B. 19

Summary Text of Session Plan Item B. 16. a

Instructions for Ranking and Rating Enemy Weapons

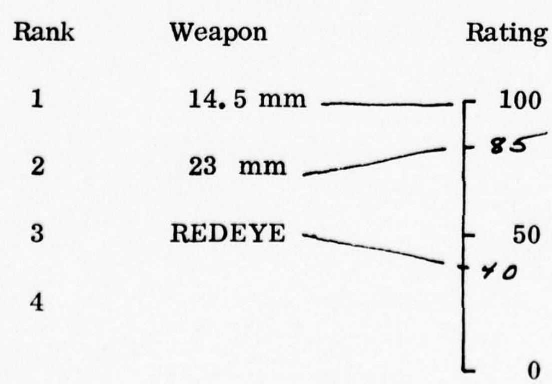
1. Select the weapon you consider to be the most threatening overall. Assign it the rank of one (1). Rate it with a value of one hundred (100).
2. Select the next most threatening weapon. Assign it the rank of two (2). Assign it a rating between zero and one hundred (0 - 100) based on its threat relative to the weapon ranked first.
3. Continue until all weapons are ranked and rated.

Exhibit B. 20

Example of Session Plan Item B. 16. b

Enemy Weapon Ranking and Rating Example

Among the weapons (14. 5 mm, 23 mm, REDEYE) Cpt. Harry Helo feels the 14. 5 mm is the most threatening, the 23 mm 85% as threatening as the 14. 5 mm and the REDEYE 40% as threatening as the 14. 5 mm. Harry's ranking and rating chart for enemy weapons appears as follows:



APPENDIX C

DATA FROM PHASE I EXPERIMENT

Table C.1

Helicopter Types Selected for Mission

Subject	Helicopter Type
6	AH-1G
7	AH-1G
8	AH-1G
9	AH-1G
10	UH-1B/C
11	UH-1C
12	AH-1G
13	AH-1G

Table C.2

Cross-Country and Attack Speeds

Subject	Running Fire Attack Speed (knots)		Knap-of-the-Earth Flight Speed (knots)	
	Quoted	Used*	Quoted	Used*
6	(45)** 0 - 90	70	(60)** 20 - 100	60
7	(80) 10 - 150	80	(65) 15 - 115	65
8	(100) 90 - 110	90	(90) 85 - 95	90
9	(100) 70 - 130	80	(30) 0 - 60	60
10	(75) 70 - 80	70	(80) 60 - 100	80
11	(80) 60 - 100	80	(80) 70 - 90	80
12	(80) 70 - 90	90	(100) 90 - 110	100
13	(60) 40 - 80	80	(100) 90 - 110	100

* Numbers in these columns represent values used in Phase II Research.

** Numbers in parentheses indicate median speed.

Table C.3

Relative Enemy Weapon Threat Ratings

	Weapon		
Subject	14.5 mm	23 mm	Redeye
6	50	89	100
7	60	85	100
8	100	90	50
9	32	100	84
10	60	90	100
11	50	100	80
12	60	100	50
13	100	90	70
Normalized Average	69	100	85

Table C.4

Unexposed Threat Factor

Subject	Sample Values									Average
6	0.0066	0.8743	0.4878	0	0.1936	0.2743	0	0.2763	0	0.2348
7	0	3.5897	0.2710	0	0.3252	0.2743	0.5405	0.2490	0.1380	0.5986
8	4.0000	0.6349	0.4336	0	0.8130	0.2195	0	1.5873	0.1372	0.8695
9	1.0000	1.2925	0.4592	0	0.7819	0	5.0000	0.4566	0	0.9989
10	0	0	0	0.1105	0	0	2.0000	0	0	0.2345
11	1.0000	5.3333	1.3953	1.5385	2.5397	0	0	1.5873	0.7937	1.5764
12	1.5000	0.4372	0	0.1105	0	0	0.2857	0	0	0.2593
13	0	0.7104	0	0	0.5464	0	0	0.0028	0.1897	0.1610

Table C.5

Maximum Threatening Range*

Subject	Weapon Type	Exposure Time (seconds)	Azimuth				
			0^{o}	45^{o}	90^{o}	135^{o}	180^{o}
6	14.5 mm	5	1000	1000	1000	1000	1000
		15	1500	1600	1800	1600	1500
		45	2000	2000	2300	2000	2000
	23 mm	5	2000	2500	2500	2500	2000
		15	3000	3000	3000	3000	3000
		45	3000	3500	3500	3500	3000
	Redeye	5	2000	2000	3000	2000	2000
		15	3000	3000	4000	4000	4000
		45	4000	4000	4500	4500	4500
7	14.5 mm	5	0	800	1200	800	0
		15	1000	1000	1500	1000	1000
		45	500	1500	1500	1500	1500
	23 mm	5	0	0	0	0	0
		15	2000	3000	3200	3000	2000
		45	3200	3200	3200	3200	3200
	Redeye	5	0	0	0	2000	2000
		15	4000	4000	4000	4000	4000
		45	4000	4000	4000	4000	4000
8	14.5 mm	5	0	0	0	0	0
		15	0	0	0	1400	0
		45	1500	1500	0	1500	1500
	23 mm	5	0	0	0	0	0
		15	0	3000	1500	3000	3000
		45	300	3000	2000	3000	3000
	Redeye	5	0	0	0	3500	3500
		15	0	0	2000	4000	4000
		45	0	0	3400	5000	5000

* All entries in meters.

Table C.5

Maximum Threatening Range*(continued)

Subject	Weapon Type	Exposure Time (seconds)	Azimuth				
			0^o	45^o	90^o	135^o	180^o
9	14.5 mm	5	0	0	0	0	0
		15	1000	2000	2000	2000	1000
		45	2000	2500	2500	2500	2000
	23 mm	5	0	0	0	0	0
		15	3000	4000	4000	4000	3000
		45	4000	4500	4500	4500	4000
	Redeye	5	0	0	0	0	0
		15	2000	3000	4000	5000	5000
		45	4000	5000	5000	5500	6000
10	14.5 mm	5	1500	0	0	0	1500
		15	1400	1500	1500	1500	1400
		45	1800	1800	1800	1800	1800
	23 mm	5	3000	2500	3000	0	3000
		15	3000	3500	3500	3500	3000
		45	3500	3500	3500	3500	3500
	Redeye	5	0	1000	2000	2800	3400
		15	0	1500	2200	3000	3800
		45	0	1600	2300	3000	3800
11**	14.5 mm	5	0	0	0	0	0
		15	1500	1500	1500	1500	1500
		45	2000	2000	2000	2000	2000
	23 mm	5	0	0	0	0	0
		15	3000	3000	3000	3000	3000
		45	3500	3500	3500	3500	3500
	Redeye	5	-	-	-	-	-
		15	-	-	-	-	-
		45	-	-	-	-	-

* All entries in meters.

** Subject 11 failed to provide Redeye data.

Table [illegible] 5

Maximum Threatening Range*(continued)

Subject	Weapon Type	Exposure Time (seconds)	Azimuth				
			0^o	45^o	90^o	135^o	180^o
12	14.5 mm	5	1200	1200	1400	1300	1400
		15	1375	1350	1200	1400	1300
		45	300	600	700	500	400
	23 mm	5	2500	2800	2700	2900	2800
		15	2000	2200	2100	2200	2300
		45	500	500	600	700	600
	Redeye	5	3000	2500	3000	2500	2500
		15	2000	3000	3000	3000	2500
		45	1500	1500	2400	1200	1000
13	14.5 mm	5	0	0	0	0	0
		15	1250	1250	1250	1250	1250
		45	1400	1400	1400	1400	1400
	23 mm	5	0	0	0	0	0
		15	2700	2700	2700	2700	2700
		45	3500	3500	3500	3500	3500
	Redeye	5	0	0	0	0	0
		15	0	0	0	4000	4000
		45	0	0	3000	4000	4000

* All entries in meters.

Table C.6

Threat Values for 14.5 mm Weapon

Subject	Exposure Time (seconds)	Range (meters) 0	600 Azimuth 0°	600 Azimuth 45°	600 Azimuth 90°	600 Azimuth 135°	600 Azimuth 180°	1200 Azimuth 0°	1200 Azimuth 45°	1200 Azimuth 90°	1200 Azimuth 135°	1200 Azimuth 180°
6	5	0	3	0	4	0	0	100	1	3	0	0
	15	25	200	700	800	500	50	300	700	300	300	450
	45	400	800	850	900	800	400	600	900	900	880	700
7	5	0	100	0	0	0	0	100	50	0	0	0
	15	200	200	400	700	200	300	100	300	300	500	300
	45	400	500	400	500	800	400	800	900	750	600	500
8	5	0	200	0	200	0	0	200	100	100	100	0
	15	200	200	300	200	750	600	200	400	400	1000	600
	45	700	700	600	800	1000	600	800	500	750	1000	600
9	5	0	45	0	5	0	50	0	0	0	0	0
	15	120	950	960	950	775	600	200	400	275	250	200
	45	999	999	900	985	997	925	795	850	700	987	890
10	5	0	0	100	0	0	0	50	0	0	0	100
	15	700	700	800	600	900	900	800	900	800	400	400
	45	1000	1000	750	1000	950	700	1000	800	950	900	900
11	5	0	0	100	50	0	0	0	0	50	200	200
	15	100	500	400	400	700	850	300	300	900	200	400
	45	700	500	800	900	700	900	300	800	850	800	900
12	5	200	400	100	300	10	100	300	300	10	50	10
	15	990	900	700	400	800	800	400	600	800	200	700
	45	1000	990	950	900	980	1000	990	950	900	970	980
13	5	0	0	0	0	0	0	0	0	0	0	0
	15	50	450	350	650	750	650	650	700	750	300	650
	45	900	800	900	975	900	750	900	850	999	800	950

Table C.7

Threat Values for 23 mm Weapon

Subject	Exposure Time (seconds)	Range (meters)										
		0	1200					2400				
			Azimuth					Azimuth				
			0^{o}	45^{o}	90^{o}	135^{o}	180^{o}	0^{o}	45^{o}	90^{o}	135^{o}	180^{o}
6	5	0	200	0	0	0	0	0	0	0	50	0
	15	40	560	880	700	500	800	560	700	990	800	300
	45	990	900	990	1000	1000	850	890	999	999	999	800
7	5	0	0	100	0	0	100	0	0	100	100	100
	15	400	300	500	200	600	800	400	200	600	400	200
	45	900	500	800	1000	1000	500	900	900	1000	500	900
8	5	0	0	0	0	100	0	0	0	0	600	0
	15	200	350	200	500	1000	700	300	400	400	850	700
	45	250	600	600	800	1000	800	400	500	600	1000	800
9	5	0	0	0	0	0	0	0	0	0	0	0
	15	600	750	920	950	700	875	300	425	790	500	250
	45	999	975	999	999	999	975	875	975	900	940	950
10	5	10	100	100	100	100	100	100	100	300	0	100
	15	800	1000	900	1000	700	1000	1000	950	1000	1000	800
	45	950	1000	1000	1000	1000	900	1000	1000	1000	1000	800
11	5	0	100	100	100	100	200	200	600	0	0	200
	15	100	600	200	800	700	800	900	800	1000	700	300
	45	800	950	950	1000	1000	950	800	800	1000	950	800
12	5	300	500	100	100	100	100	300	50	100	20	50
	15	1000	800	850	890	900	980	850	600	700	600	500
	45	1000	1000	990	1000	800	1000	1000	990	950	700	950
13	5	0	0	0	0	0	0	0	0	0	0	0
	15	50	400	550	500	150	550	450	500	450	250	300
	45	800	975	975	995	980	950	750	900	975	780	900

Table C.8

Threat Values for Redeye Weapon

Subject	Exposure Time (seconds)	Range (meters)										
		0	1400					2800				
			Azimuth					Azimuth				
			0^{o}	45^{o}	90^{o}	135^{o}	180^{o}	0^{o}	45^{o}	90^{o}	135^{o}	180^{o}
6	5	0	0	0	0	0	0	0	0	0	0	0
	15	800	900	900	999	1000	1000	900	990	999	1000	1000
	45	1000	1000	1000	1000	1000	1000	900	1000	1000	1000	1000
7	5	0	0	100	100	100	100	0	0	100	0	0
	15	900	900	900	900	750	1000	100	900	500	1000	900
	45	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	5	0	0	0	0	100	100	0	0	0	0	0
	15	200	150	200	500	750	600	0	0	200	800	800
	45	600	300	600	500	1000	1000	300	200	500	1000	1000
9	5	0	0	0	25	0	100	0	0	0	0	10
	15	875	300	50	500	955	940	15	0	75	900	995
	45	1000	450	700	999	999	999	25	910	100	999	999
10	5	0	0	200	100	200	800	0	100	100	400	200
	15	800	0	400	400	900	1000	0	800	900	1000	1000
	45	1000	200	100	1000	1000	1000	0	0	1000	900	1000
11	5	0	0	100	0	100	700	1000	0	0	50	700
	15	200	0	150	500	900	900	0	200	0	950	800
	45	1000	200	100	750	950	1000	0	100	200	800	900
12	5	5	10	50	10	10	400	10	50	5	100	50
	15	950	600	700	700	900	980	400	100	100	100	300
	45	1000	900	200	950	900	1000	900	800	300	800	950
13	5	0	0	0	0	0	50	0	0	0	40	350
	15	90	0	0	10	350	250	0	0	0	525	650
	45	990	350	350	350	850	990	10	0	350	950	990

APPENDIX D

PHASE II EXPERIMENTAL MEDIA

Exhibit D.1

Experimental Session Plan

Part A Phase II Route Selection Session

A.1 Present introduction

A.2.a Pass out TOW Weapon System Description

A.2.b Present discussion of TOW Description

A.2.c Pause to permit subjects to review TOW Description

A.3.a Pass out Map Boards

A.3.b Present discussion of Map Boards

A.3.c Pause to permit subjects to familiarize themselves with Map Boards

A.4 Present discussion of miscellaneous route preparation materials

A.5.a Pass out route preparation overlay and Route Description Form for first route

A.5.b Present instructions for using Route Description Form and for preparing route sketch

A.5.c Pause to permit subjects to complete first route description

A.6 Repeat steps A.5.a and A.5.c for routes two, three, and four. Let each subject work at his own pace

A.7 Collect all material from each subject

Part B Phase II Route Evaluation Session

B.1 Present introduction

B.2 Pass out supply package

B.3.a Present instructions for transferring routes

B.3.b Pause to permit subjects to transfer routes

B.4.a Present instructions for the use of computer prepared route overlays and answer sheets in performing route evaluations

B.4.b Pause to permit subjects to perform route evaluations

B.5 Collect all material from each subject

Exhibit D. 2

Summary Text of Session Plan Item A. 1

Introduction to Route Selection Session

Gentlemen, we now come to the part of the experiment which you will probably find to be the most interesting of all. The slides, which I know you've grown a little tired of, are all behind us now. For the rest of the session we will be concentrating in an area that will permit you to express your own style-- to demonstrate the creativity that makes you a successful military aviator. I am going to present you with a series of realistic tactical situations and ask you to prepare a sketch of a route you would follow while executing a mission in response to each of the situations.

We will start by providing you with detailed information about the armament system that will be available to you during the missions. We will then provide each of you with a map board that will illustrate not only the terrain and vegetation in the mission operations area but also the overall tactical situation which you will face. We will also provide a variety of materials, such as scales and marking pens, which will be of use in preparing your route sketches. Finally, a series of four route selection situations will be defined for each of you, from which four different route sketches may be prepared. Blank acetate overlays will be provided for the route sketches, and answer sheets will be made available to record certain data about each route.

Now, as we commence the exercise let me remind you of several items which are very important to the success of the experiment. First, as I have

said before, there are no right or wrong answers. We want only your opinion as a highly qualified military aviator. Your skill as a pilot is not in question. Second, I want you to recall the scenario I outlined for you at the beginning of the session. As you prepare your route sketches please remember not only that the missions are being conducted in response to particular situations but also that the scenario provides a frame of reference within which all the situations arise. We are interested in your actions in a hypothetical mid-intensity warfare environment; one in which you are providing direct fire support for an armored unit engaged with a highly lethal enemy.

Exhibit D. 3

Example of Session Plan Item A. 2. a

Section IV. XM26 (TOW) ARMAMENT SUBSYSTEM

1-9. Description

The purpose of the XM26 (TOW) helicopter armament subsystem (fig. I-2) is to provide the Army with a highly mobile, airborne, heavy point fire weapon system. This system uses the TOW (tube launched, optically tracked, wire command link) guided missile. The XM26 is designed to replace the M22 subsystem. It consists of the following major assemblies—

a. Stabilized Sight/Sensor. The stabilized sight/sensor (A, fig. I-2) mounted in the helicopter nose is the key to the XM26 subsystem. This gyro-stabilized sight enables the gunner to keep the crosshairs of his sight on the target, regardless of helicopter vibration and maneuvers. Through the sight, the gunner establishes and maintains the line of sight which the missile follows to the target.

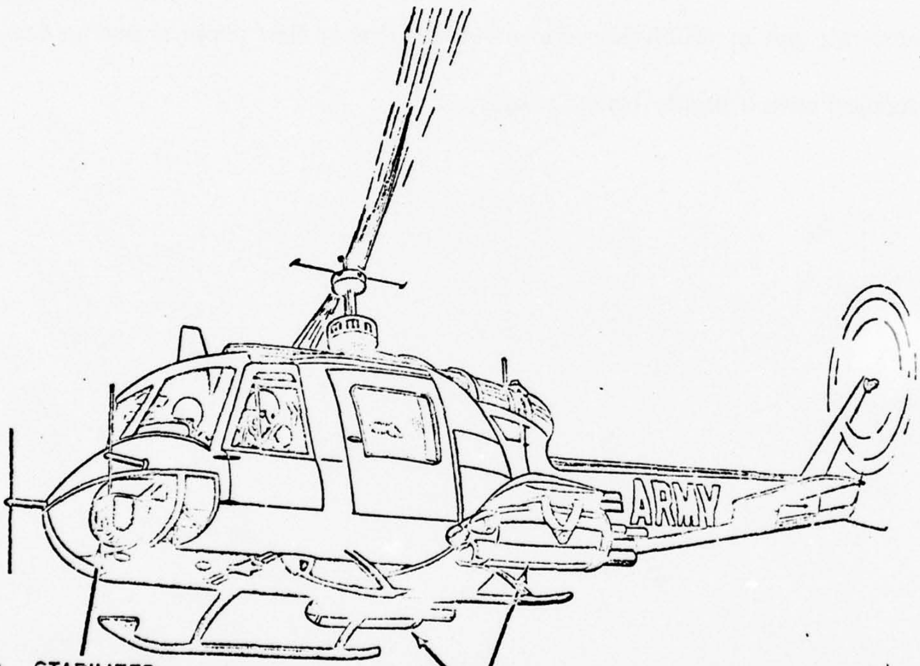


Figure I-2. XM26 armament subsystem on UH-1.

b. Launchers. The missile container is attached to the helicopter bomb rack. There is a launcher containing three missiles (B, fig. I-2) on each side of the UH-1 helicopter. The launchers are trainable in elevation only by hydraulic actuation.

c. Electronics. The electronic assemblies contain necessary circuitry for the operation of all XM26 subsystem assemblies. The circuitry is built into three separate chassis—*servo electronics*, *auxiliary electronics*, and *command signal generator*.

d. Power Supply. Power for the subsystem is produced through an inverter located in the helicopter engine compartment. The inverter uses 24 volts DC from the helicopter emergency power and converts it into 115 volts AC 400 cycle, three-phase power for the XM26 subsystem. If emergency power is needed as helicopter prime power, the circuit is designed so that the XM26 subsystem can be switched out of the circuit.

e. Missile. The TOW missile round is launched directly from the missile container (fig. 1-3), without an additional launch tube.

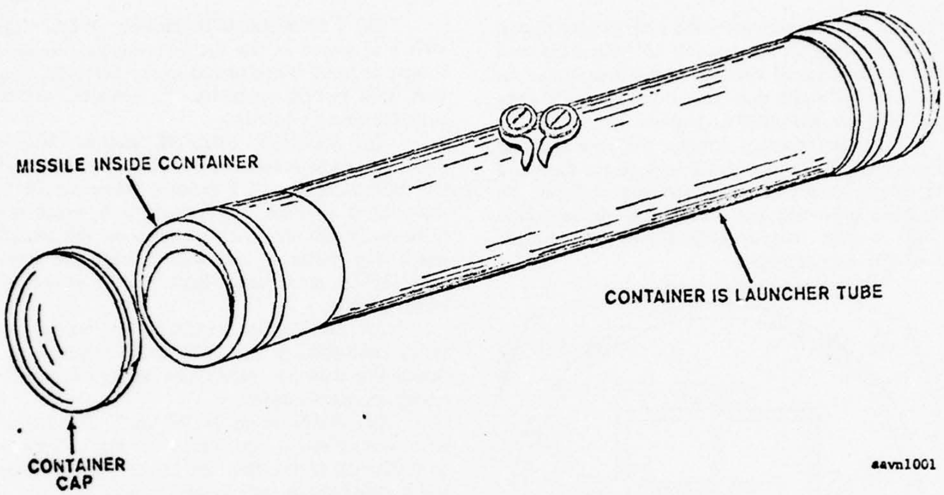


Figure I-3. Missile and container.

f. Cockpit Controls and Displays. The cockpit controls and displays located in the cockpit allow for ease of operation by the gunner and do not interfere with the flight controls of the helicopter. Figure I-4 shows cockpit controls and displays in a UH-1 helicopter; however, the XM26 subsystem is adaptable to the AH-1 attack helicopter. Power and armament controls are mounted on

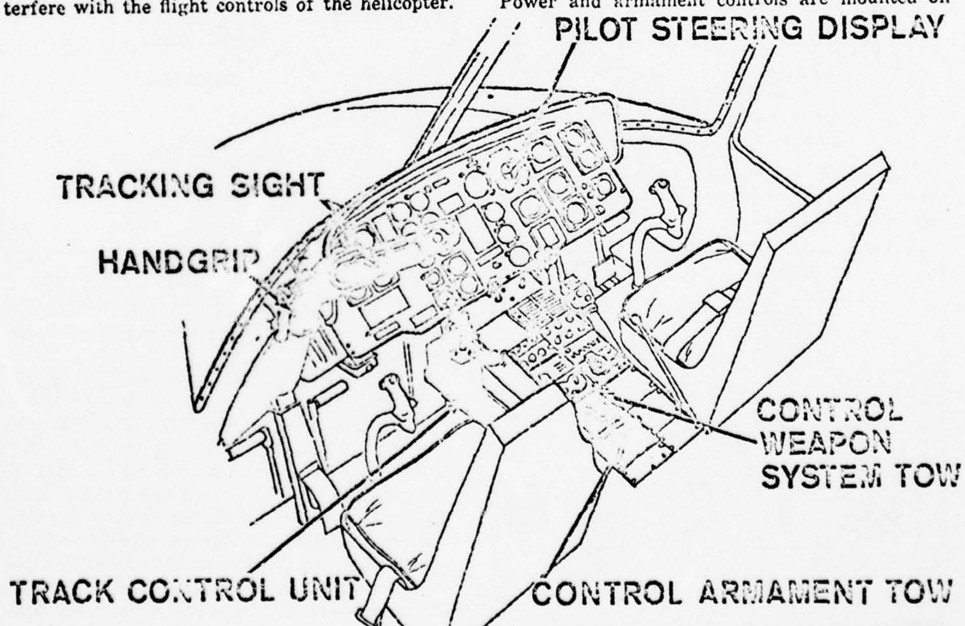


Figure I-4. Cockpit controls and displays in UH-1 helicopter.

the console between the pilot and gunner's seat. These are within easy reach of both pilot and gunner. Additional controls and displays are located on the sight extension tube, gunner's armrest, and the helicopter instrument panel.

(1) *Pilot steering display.* The pilot steering display (fig. I-5) provides attack status data and an azimuth steering signal for missile firing. So that the pilot will not exceed the gimbal angle limits during maneuvering flight, it indicates platform gimbal angles.

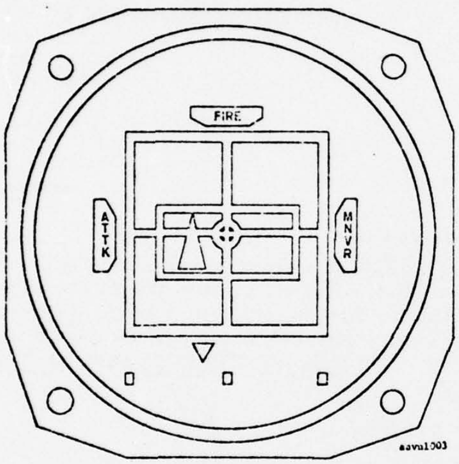


Figure I-5. Pilot steering display.

(2) *TOW armament subsystem control panel.* The TOW armament subsystem control panel (fig. I-6) has—

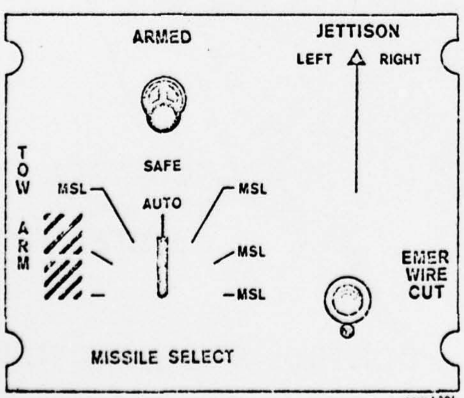


Figure I-6. TOW armament subsystem control panel.

(a) *SAFE/ARMED switch.* When this switch is placed in the SAFE position, a missile cannot be fired. When placed in the ARMED position, this switch completes the circuitry necessary for firing a missile.

(b) *MISSILE SELECT switch.* Missile selection can be manual or automatic by means of the MISSILE SELECT switch. When placed in the AUTO position, the system will select the next ready missile. Each position on the switch has a flag indicator that will indicate the presence (MSL), or absence (barber pole) of the selected missile.

(c) *JETTISON switches.* In an emergency, activation of the JETTISON switches jettisons the launcher assemblies to improve helicopter maneuverability.

(d) *EMERgency WIRE CUT.* In case of wire entanglement or failure of the automatic wire cutting device, the emergency wire cut control permits the gunner to cut the wire.

(3) *TOW weapon subsystem control panel.* The TOW weapon subsystem control panel (fig. I-7) has—

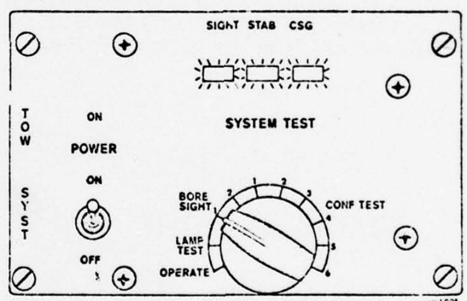


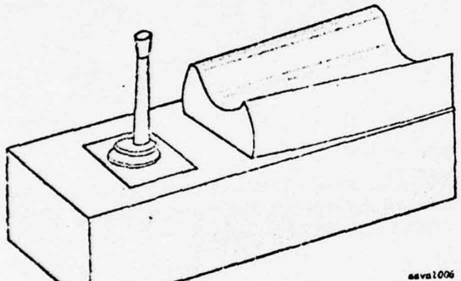
Figure I-7. TOW weapon subsystem control panel.

(a) *POWER ON/OFF switch.* In the ON position, full operating power is applied to the subsystem.

(b) *SYSTEM TEST switch.* This 10-position switch is used to determine the operational status of the weapon subsystem. The first position (OPERATE) switches out all system test circuitry; the switch must be in this position to fire a missile. The second position (LAMP Test) applies power to all indicator lamps. The next two positions (B1 and B2) are used in performing boresighting checks and alinement. The last six positions of the switch are used to perform system selftest. Results of the selftest are indicated on the three flag indicators above the switch. A GO indication will be displayed when a

particular test has been satisfactorily completed. The three indicators used are—SIGHT, for the stabilized sight/sensor unit; STAB, for stabilization electronics; and CSG, for missile guidance electronics.

(4) *Track control unit.* The track control unit (FIG. I-8) is designed for right-handed operation by the gunner to provide control inputs to the TOW sight system for manual acquisition, tracking, and stow positioning of the sight. The tracking control stick and control switch have been designed into a small unit separate from the armrest. The position of the control unit may be adjusted to accommodate different sized gunners.



aava1006

Figure I-8. Track control unit.

(5) *Gunner's handgrip.* The gunner's handgrip (fig. I-9) provides a means of stabilization for the gunner, switching function controls, and a designation pointer display. The handgrip is fixed to the left side of the sight unit relay column near the upper rotary joint. The switching functions are short or long range selection, high or low magnification selection, camera control, reticle brightness control, attack mode selection, and trigger. The trigger is a recessed, momentary, snap-action pushbutton. The designation pointer display is a small pencil-shaped pointer that indicates where the sight is pointing. It is used in the heads-up mode for gross positioning of the sight prior to headsdown acquisition. It is located over a moving card display that indicates the azimuth position of the sight relative to a fixed scale.

I-10. Operation

a. In combat, the helicopter gunner acquires and tracks a target through the stabilized sight/sensor. A display on the instrument panel (fig. I-5) will indicate to the pilot each phase of the engagement; e.g., attack, fire, and maneuver.

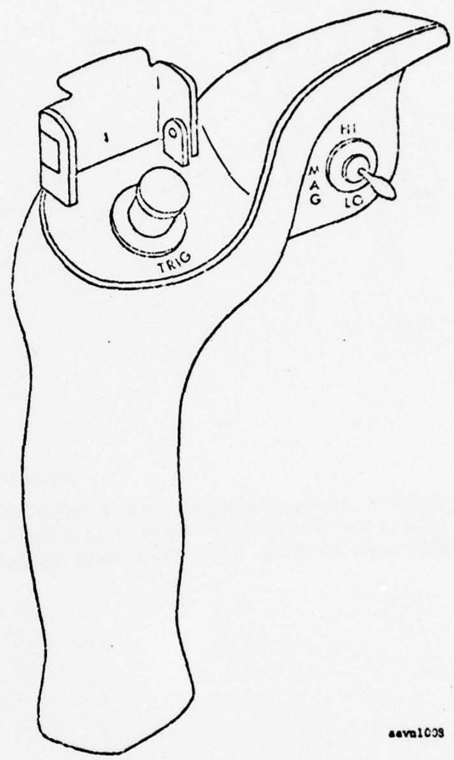


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Figure I-9. Handgrip.

Also indicated are limitations of the evasive maneuvers that the pilot may perform.

b. Easily operated, viscous damped controls (fig. I-8) enable the gunner to maintain the sight/sensor pointing direction without regard to the angular motion or vibration of the helicopter.

c. The TOW missile is fired into the field of view of the stabilized sight/sensor. The stabilized sight/sensor "senses" missile flightpath deviation from the line of sight maintained by the gunner. These deviations are sent (in terms of electronic impulses) to the command signal generator, then converted into corrective commands and sent to the missile by thin wires that are payed out in flight. These corrective commands guide the missile back to the line of sight and on to the target (fig. I-10).

I-11. Logistical Support

TOW armament subsystem equipment will be de-

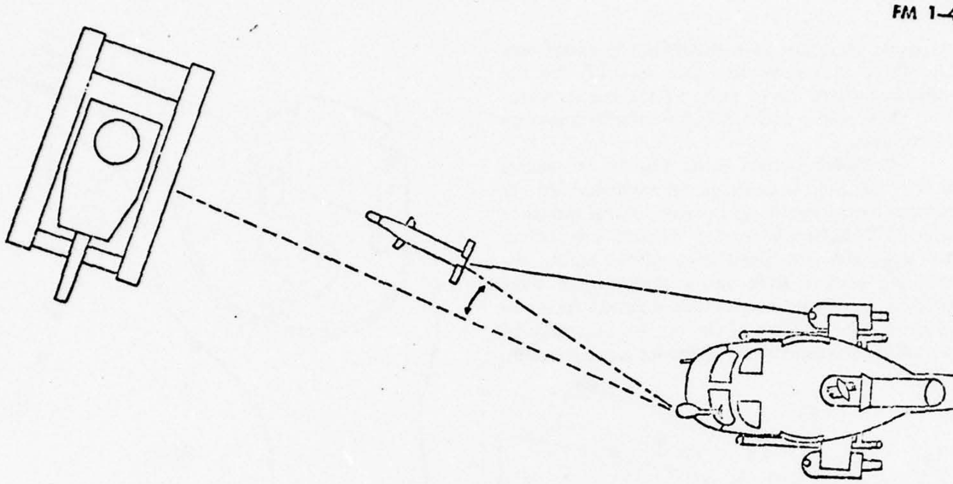

Figure I-10. Weapon concept.

signed to include a completely built-in selftest capability that will isolate faults down to a removable major assembly. Under the current planned concept, the aircraft armament repairman will remove and replace the defective assembly indicated by the built-in selftest.

Auxillary Data

XM26(TOW) Armament Subsystem
(Unclassified--for illustrative purposes only)

Time required to fire a round after the aircraft has achieved its launch heading--5 seconds.

Maximum aircraft heading deviation from line of flight of missile after launch--40 degrees.

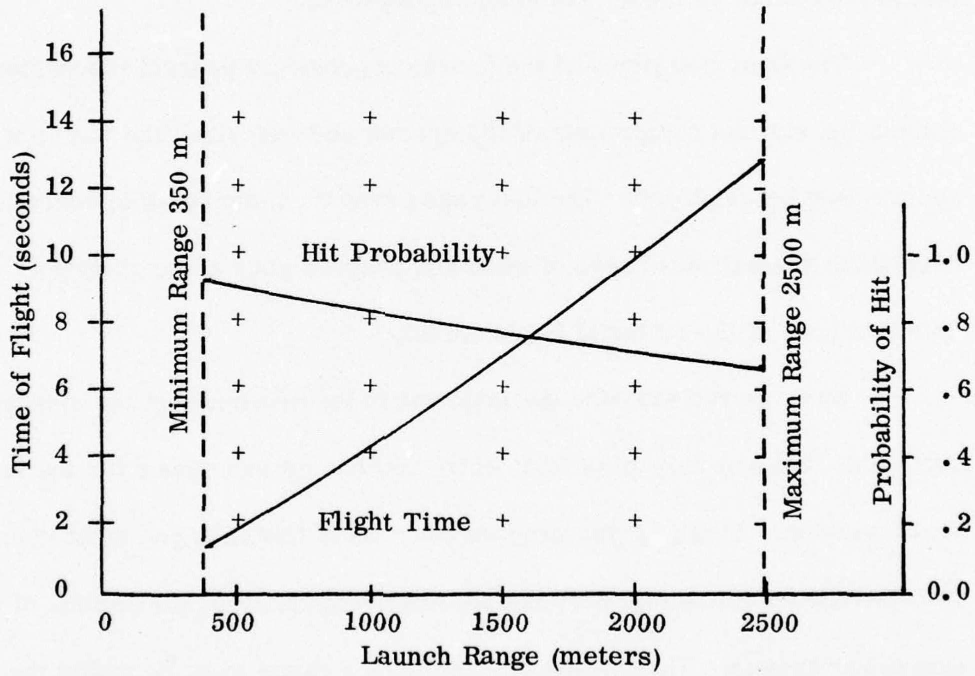

Exhibit D. 4

Summary Text of Session Plan Item A. 2. b

Discussion of TOW Weapon System

If you will examine your supply box, you will find a brochure describing the armament system we want you to visualize as being your sole source of fire-power while executing the four missions that we are going to define. The system is the XM26, or TOW, armament subsystem.

The first five pages of the brochure present a general discussion that defines the various components of the system and describes the way in which the system may be employed. The last page presents some detailed operational data which you will have need of when you prepare your route sketches. Please note that none of the material is classified.

Now, as you examine the material in the brochure let me emphasize two points that are very important which you should remember for the remainder of the session. First, as you prepare your route sketches you must insure that they include an attack that does not violate the operational limitations of the armament system. This means that the launch range must be within the minimum and maximum ranges specified for the missile. Furthermore, you must have the target in sight for a sufficient time prior to launch to permit accurate aiming. Finally, while the missile is flying you must continue to guide it. This means that you must maintain visual contact with the target and that the gimbal limits of the tracking mechanism limit the amount by which your flight path may deviate from that of the missile.

Second, the operational data to be used in defining the attack limits I have just discussed are those that appear in the weapon system brochure. However, if you are already familiar with the TOW, you will note that the operational data in the brochure are not exactly those with which you are familiar. I have revised the correct data slightly in order to keep this experiment unclassified. Thus, those of you who are familiar with the system must be especially careful to use the brochure data. Otherwise, we might obtain route sketches which are unacceptable as far as the experiment is concerned.

Exhibit D. 5

Description of Map Boards Used in Session Plan Item A. 3

As explained in Chapter 4 and Appendix A, a total of four unique map boards were required for the Phase II Experiment Route Selection Session. Map board A was used by subjects 6 and 10, map board B by subjects 7 and 11, and so on. Each map board was constructed of the following materials:

1. One (1) piece of heavy white poster board, measuring 20 inches by 12 inches;

2. One (1) battlefield contour map on white paper stock, measuring 14 1/2 inches by 7 1/2 inches;

3. One (1) forest overlay on clear acetate, measuring 14 1/2 inches by 7 1/2 inches;

4. Two (2) line of sight overlays on clear acetate, each measuring 14 1/2 inches by 7 1/2 inches; and

5. One (1) protective sheet of clear acetate measuring 18 inches by 10 inches.

The quoted dimensions of the contour map and overlays are the dimensions of the boundaries of the battlefield, and examples of these materials may be found in Appendix A. A representation of the complete map board may be found at Exhibit D. 6.

The reader may note by examining Exhibit D. 6 that the finished map boards were potentially very difficult to interpret. However, a coloring scheme was used that alleviated this difficulty. Unfortunately, the coloring scheme is not apparent in the exhibit.

As presented to the subjects, the forested regions were outlined in green, the areas intervisible with enemy weapon number one were outlined in red and the areas intervisible with enemy weapon number two were outlined in blue. It was found that after sufficient exposure to the map boards and instructions for interpreting them the subjects had no difficulty in visualizing the situation described by the map board.

The acetate overlays used in constructing the map boards were prepared from plots of forested regions and intervisibility areas originally produced by the computerized methods described in Appendix A. The plots, originally on a translucent material, were reproduced on special 8 1/2 x 11 acetate material using the Xerox process. Since the plots were oversized, each overlay actually consisted of two acetate sheets, which together covered the entire battlefield. Also, since the Xerox process normally produces slightly reduced copy, special adjustments were made to the machine that was used in order to obtain exact copies.

AD-A045 094 OHIO STATE UNIV COLUMBUS SYSTEMS RESEARCH GROUP F/G 1/2
THE HELICOPTER ROUTE SELECTION MODEL (DYNFLITE).(U)
AUG 76 G M CLARK, D C HUTCHERSON, D C BITTERS DAAG25-70-C-0311
UNCLASSIFIED RF-2978-FR-76-4(0) NL

5 OF 6
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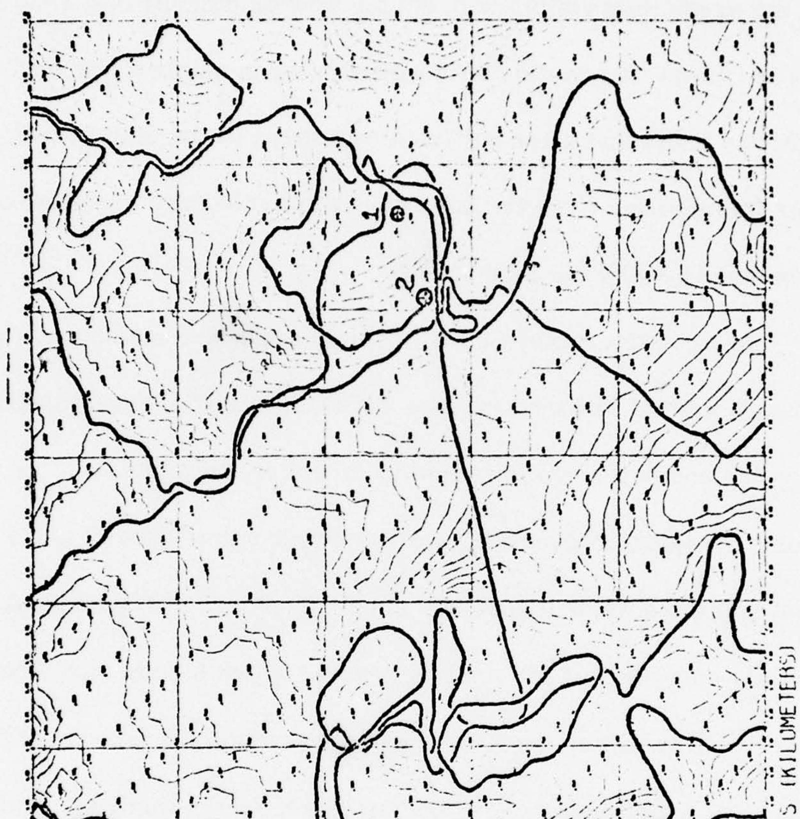
Exhibit D. 6

Example of Session Plan Item A. 3. a



Original size of map: 7. 5 x 14. 5 inches

Map Board B

Exhibit D. 7

Summary Text of Session Plan Item A. 3. b

Discussion of Map Boards

Now that you have become familiar with the armament you will be using on your missions, let us find out where the missions are going to be flown. I am handing each of you a map board that will do this job.

You will note that there is a lot of information on your map board; and, at first glance, it appears quite complex. However, after you have had a chance to become familiar with it, you will find that the information presented is very valuable to you in your route selection task.

First, you will note that your map is of an area that is five kilometers wide and ten kilometers long, located in the Fulda Gap region of West Germany. The contour plot was prepared by computer using actual elevation data provided by the Army Map Service. It not only shows contour lines at five meter elevation intervals, but it also indicates the elevation of specific points located at regular intervals throughout the area.

Grid coordinates of any point can be determined from the scales appearing along each boundary of the map. The major division of these scales is the kilometer, but each kilometer is also divided into five parts so that a scale reading is available at intervals of two-tenths of a kilometer. For ease of orientation let us assume that north is to the top and east is to the right as is customary.

Now, the map boards also indicate regions of the battlefield that are covered with woods and forests. These regions are outlined in green and are the same for each one of you. Trees within these forested regions average twenty meters in height while outside the forested regions the terrain is covered only with grass and scattered bushes.

Finally, you will note that two enemy weapon positions are indicated on your map board and are labeled "1" and "2". Each of you has a different set of weapon positions.

Associated with each of the enemy positions is an overlay that we will call a line of sight or LOS map. These LOS maps show up on your map boards as groups of irregularly shaped areas outlined either in blue or in red. The red LOS map is associated with the enemy position labeled with the red numeral while the blue LOS map is associated with the position labeled with the blue numeral.

Now, what do the two LOS maps reveal about the battlefield? Suppose you select any position on the battlefield and imagine that you are flying a knap of the earth flight profile. This means that you are trying to fly as low as possible at each point along your flight path, climbing enough to just clear the tops of trees while over forested regions and dipping even below tree top altitude while over open terrain. The LOS maps indicate how much of your flight profile will be exposed to the two enemy weapons. For example, suppose you select a position that is within one of the blue LOS areas. This means that your flight path at this point is exposed to the enemy weapon labeled with the blue numeral.

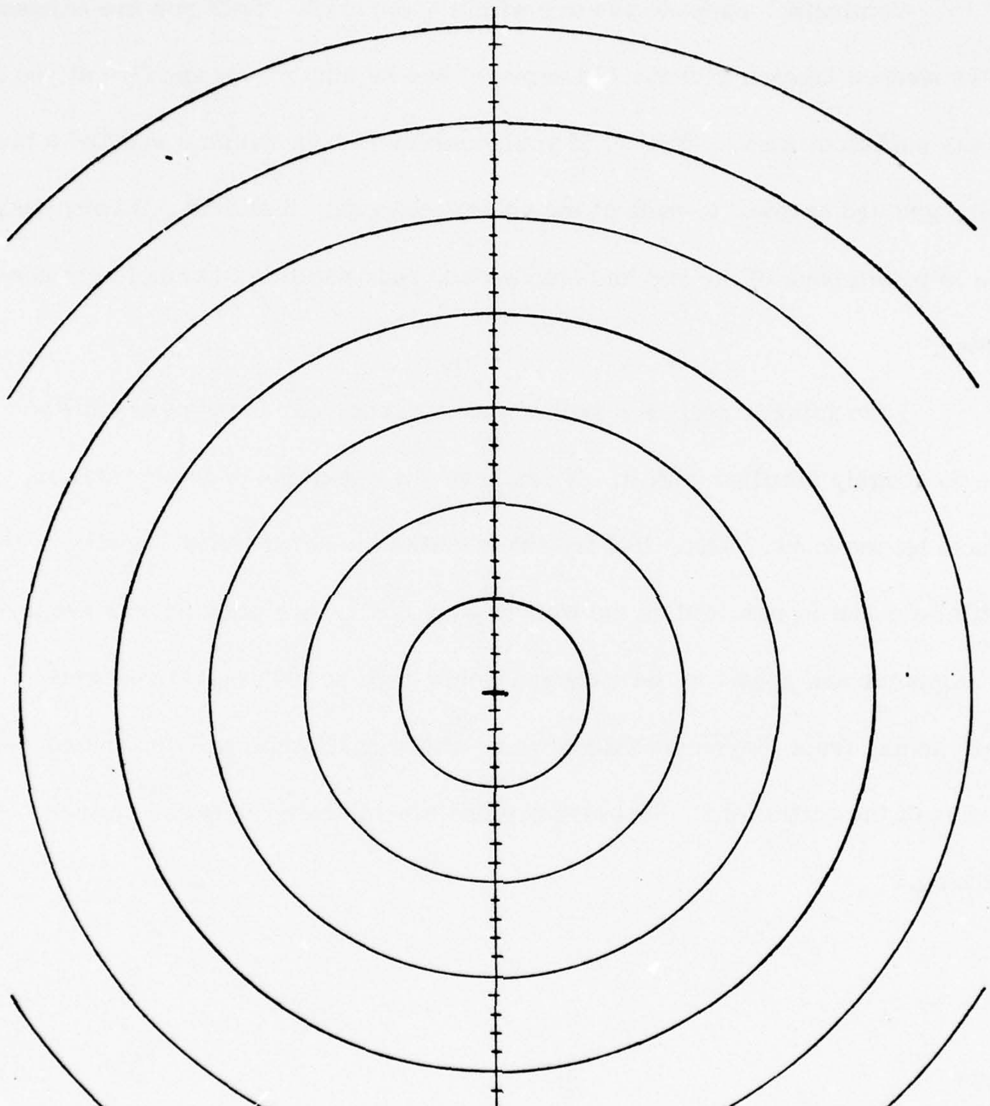
Not only can he detect you at this point but he may also engage you with direct fire. Of course, you are also provided with these same opportunities.

Continuing, suppose you are within a red area. Then you are exposed to the weapon labeled with the red numeral and he may detect and fire at you if he has sufficient time. Finally, if your position is both within a red and a blue area, you are exposed to each of the enemy weapons. Similarly, if your position is within none of the red and blue areas, your position is completely concealed.

I am going to stop now and let you examine your map board until you are thoroughly familiar with it. If you have any questions of interpretation, please let me know. Also, feel free to examine the perspective drawing of the battlefield that is mounted on the wall to your left. This drawing was prepared by computer and presents the view you would have at 3000 feet if you were approaching from the northwest and were still two kilometers from the nearest corner of the battlefield. Forested regions are indicated in green on the drawing.

Exhibit D. 8

Examples of Materials in Session Plan Item A. 4



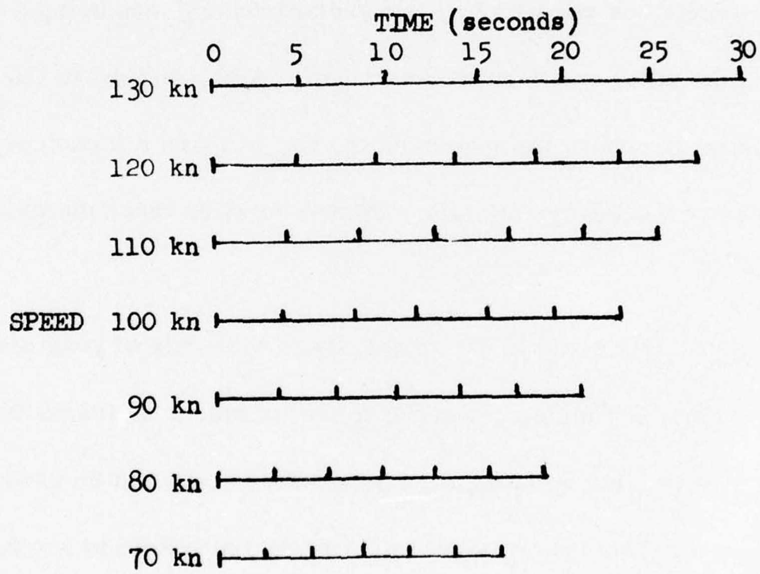

TIME (seconds)
0
5
10
15
20
25
30
130 kn
120 kn
110 kn
SPEED
100 kn
90 kn
80 kn
70 kn

Exhibit D. 9

Summary Text of Session Plan Item A. 4

Discussion of Miscellaneous Route Preparation Materials

Now that you have examined your map boards we are almost ready to begin the route selection exercise. However, before we start let me draw your attention to some materials you will need in order to do the job correctly.

In your supply box you will find two acetate scales, one being a fairly large scale and the other one being rather small. Also, clipped to the back of the Enemy Weapon Brochure we used earlier, you will find a launch performance envelope for the Redeye missile. Please examine these materials as I discuss them.

The large acetate scale is drawn exactly to the scale of your map board. Each ring represents 500 meters, and there are tic marks at 100 meter intervals along the straight line splitting the rings. This scale can be used anytime you need to know the distance from one point on the battlefield to another. In particular, you should use this scale to determine a firing point that is within the effective range of the TOW missile you are employing.

The small acetate scale contains seven time and distance charts, one for each of seven flight speeds. Again, the scale is drawn exactly to the scale of your map board and indicates the distance you would travel at a particular flight speed in a given amount of time. This scale is to be used in conjunction with the missile flight time graph that forms the last page of the TOW weapon

system description you examined earlier. For example, suppose you elect to fire your TOW missile from a range of 1500 meters while flying at 100 knots. From the flight time graph you find that the missile requires seven seconds to impact from this range. Then from the time and distance scale for 100 knots, you find that you will travel approximately 300 meters during this time. Consequently, you will be 1200 meters from the target when the missile impacts if you continue to fly toward the target during missile flight. Data such as these are needed in constructing accurate sketches of routes that you select.

Finally, the Redeye launch performance envelope that we have already discussed is also drawn to the scale of your map board. If you place this envelope over one of the enemy positions and orient it in a given direction, you will be able to determine the areas in the vicinity of the weapon in which effective fire can be delivered against a helicopter approaching from the indicated direction. This information may be valuable to you in judging various route alternatives in the vicinity of a Redeye weapon.

Exhibit D. 10

Summary of Route Selection Situations Presented
in Session Plan Items A. 5 and A. 6

Subject Pair	Route Situation	Map Board	Description		Starting Coordinates **	
			Weapon 1	Weapon 2	X	Y
6, 10	1	A	*14. 5 mm	23 mm	0	4000
	2		*14. 5 mm	23 mm	6000	5000
	3		14. 5 mm	*23 mm	0	4000
	4		14. 5 mm	*23 mm	6000	5000
7, 11	1	B	23 mm	*14. 5 mm	0	2000
	2		23 mm	*14. 5 mm	5500	5000
	3		*23 mm	14. 5 mm	0	2000
	4		*23 mm	14. 5 mm	5500	5000
8, 12	1	C	*14. 5 mm	23 mm	0	2000
	2		*14. 5 mm	23 mm	5500	5000
	3		14. 5 mm	*23 mm	0	2000
	4		14. 5 mm	*23 mm	5500	5000
9, 13	1	D	*23 mm	Redeye	0	2000
	2		*23 mm	Redeye	5500	5000
	3		Redeye	*23 mm	0	2000
	4		Redeye	*23 mm	5500	5000

* Weapon to be attacked

** Terminal coordinates of all routes is the X = 0 map boundary.

Exhibit D. 11

Example of Session Plan Item A. 5. a

Map Board B

ROUTE DESCRIPTION FORM

I. Subject Number 7 Route Number 1

II. Starting Coordinates: X = 0 Y = 2000

III. Terminal Boundary: X =0

IV. Weapon Descriptions

	Type	X	Y
1.	23 mm	8700	2500
2.	14.5 mm	8100	2300

V. Weapon to be Attacked 2

- -

VI. Attack Description

A. Mode of Attack (check one)

1. Hover Fire ____________

2. Running Fire __________

B. Approximate launch point coordinates (meters)

X = ____________ Y = ______________

C. Approximate launch range (meters) ____________

D. Approximate missile flight time (seconds) ____________

E. Approximate probability of hit ______________

F. What factor(s) led to the selection of the mode of attack indicated in part (A) above?

Exhibit D. 12

Summary Text of Session Plan Item A. 5. b
Instructions for Preparing Route Sketches

I am now handing each of you the materials that you will need in preparing your first route sketch. As you can see there is a form called the Route Description Form and there is a piece of clear acetate. The route description form defines the route you are to select while the acetate is to be used to prepare your route sketch.

First, I want each of you to attach the clear acetate to your map board using the tape I am passing around now. You will notice that the acetate has markings to indicate where the corners of the battlefield area are to be placed under the overlay. You will also notice that the overlay is marked with your subject number and route number, in this case route number one.

Now I want you to examine the route description form. First, you will see that I have filled in all the blanks above the dotted line. The subject number and route number have been recorded, and other information is provided to define the route selection situation. First, the starting coordinates of the route are provided and you should make sure that your route actually does start from the specified point. For this first route each of your starting points will be somewhere on the western boundary of the battlefield.

Next, the terminal position of the route is specified. This position is the point at which your route should terminate after starting from the specified initial position and passing through the attack position that you choose. For

this route the terminal position is anywhere on the western boundary. Please make sure that your route actually does terminate there.

Next, the weapons that you will face while executing the route are specified. Weapon number one corresponds to the position labeled "1" on your map board, and the coordinates that are recorded should be those of that position. Similarly, weapon number two corresponds to the position labeled "2". The types of weapons specified have been selected from those that we studied earlier.

Finally, the weapon position you are to attack is identified. It may be either position number one or position number two, but in any case the weapon that is not to be attacked can be thought of as a supporting weapon which you must be aware of.

Now, below the dotted line are several data items which I want you to record after you have completed your route sketch. You will note that you may select either hover fire or running fire, but I would like for you to tell me what factors you considered in making the choice. The other data can be determined by using the scales we discussed earlier or by using the TOW weapon system operational data with which you have been provided. Please try to determine these data as accurately as possible.

In preparing your route sketch you may use the orange grease pencil that is in your supply. Be sure and place arrow heads on the sketch so that I will be able to determine your intended direction of motion at all points. Also, please indicate with a circle the position you select as the firing point for your

attack. If you need to make corrections to your sketch, you will find a cotton pad in your supply box for erasures.

You may start your first sketch now. For the remainder of the session you will be working at your own speed. Therefore, when you complete your first sketch let me know. I will collect your data and give you the material you need for your second sketch. Please take as long as you like on each sketch. Also, if you have a question, please let me know.

Exhibit D. 13

Summary Text of Session Plan Item B. 1

Introduction to Route Evaluation Session

Good morning, gentlemen. It is really a pleasure to see your smiling faces once again. I hope the early hour doesn't reduce your enthusiasm for the task that is facing us this morning.

As you will recall, about a month ago we met, and at that time we went through a two-hour session in which we gathered very specific and detailed information concerning your own personal feelings about helicopter route selection. Since that time I have been very busy reducing that data and using it in a model that has been developed to predict what we think you will select as a route, given a particular tactical situation. The purpose of the session this morning is to see how well we have done.

The sketches of the four routes you prepared in the earlier session are going to be returned to you shortly, along with a series of alternative routes prepared by the computer model. There will be a different set of alternates for each of the four route selection situations. Once you have this material in hand, you will be instructed in a method of evaluating the alternatives. You will then analyze the alternatives according to the instructions, and finally you will record your evaluations on forms that I will provide.

At this point let me reiterate a statement I made several times during our first session which is just as appropriate today. We are not attempting to judge your skill as an aviator in this experiment. Therefore, there are no

right or wrong answers. Instead, we want your opinions as highly qualified military aviators. We want your honest evaluation of the alternatives relative to the routes you selected. With this information we will have a yardstick by which our model may be judged. We will then be able to decide either that we have an adequate model or that we must continue to refine the model. Your conscientious cooperation in this exercise is therefore very critical to our success.

Exhibit D. 14

Description of Materials Used in Session Plan Item B. 2

The material packet handed to each subject at the beginning of the Route Evaluation Session contained the following 31 items:

1. Four (4) acetate overlays;
2. Four (4) map sheets;
3. Four (4) answer sheets;
4. Sixteen (16) translucent overlays;
5. One (1) TOW Weapon System Description;
6. One (1) felt tip marker; and
7. One (1) lead pencil.

Examples of the translucent overlays and answer sheets appear at Exhibit D. 15 while the TOW Weapon System Description appears at Exhibit D. 3. The map board at Exhibit D. 6 is similar in appearance to the map sheets in the packet. However, because of format requirements all map sheets and overlays, as presented, are reduced in size from their original dimensions of 7 1/2 inches x 14 1/2 inches. Furthermore, the original coloring schemes, which were of benefit to the subjects during the experiment, were lost during the reduction process.

Descriptions of the use of the materials and of the coloring schemes used are presented at Exhibits D. 16 and D. 17.

Exhibit D. 15

Examples of Materials in Session Plan Item B. 2

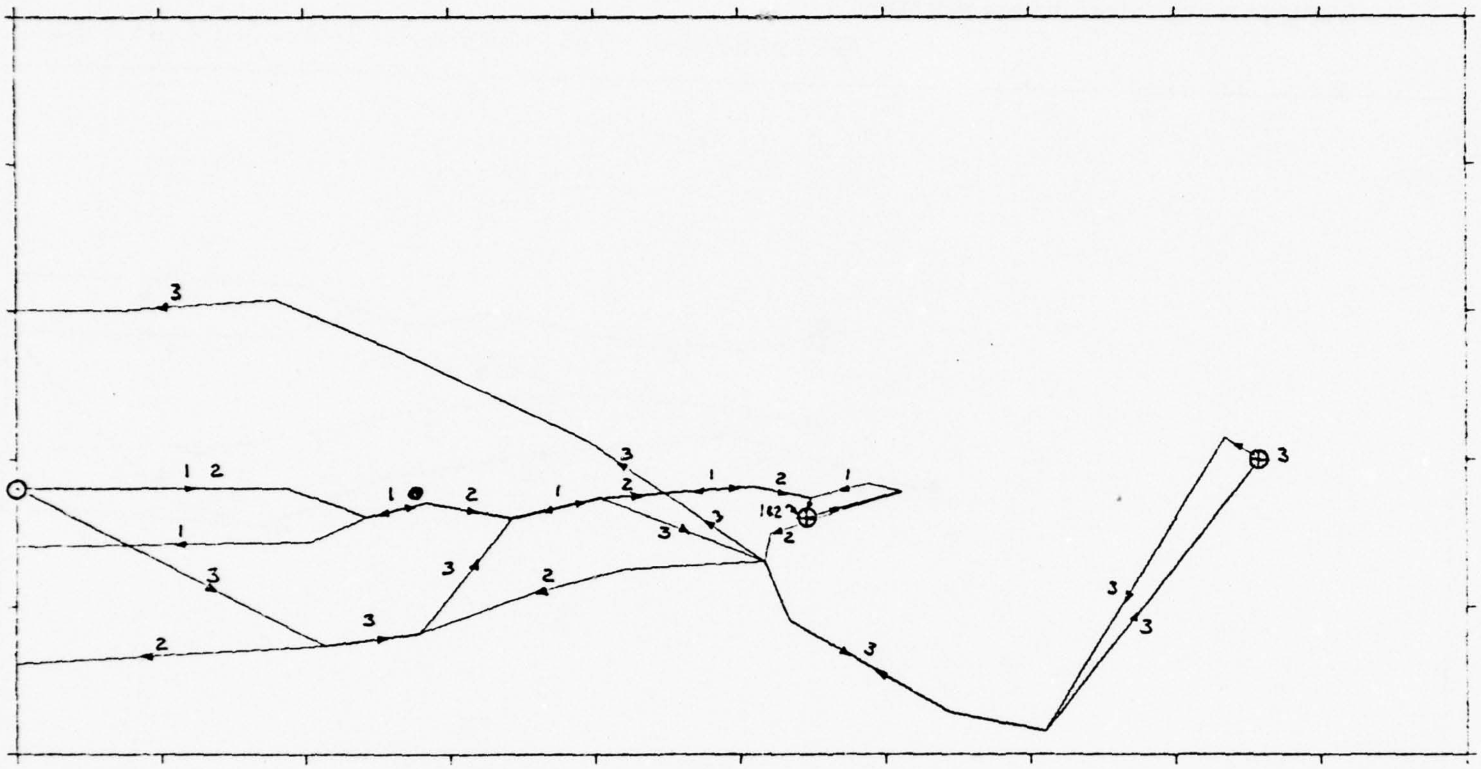
Route Evaluation Form

Subject Number 7 Route Number 1

Route Alternative Number	Ranking*				Rating**
	Indifferent (100)	Almost Indifferent (95-99)	Mildly Prefer (70-94)	Strongly Prefer (0-69)	
1					
2					
3					
4					
5					
6					
7					
8					
9					

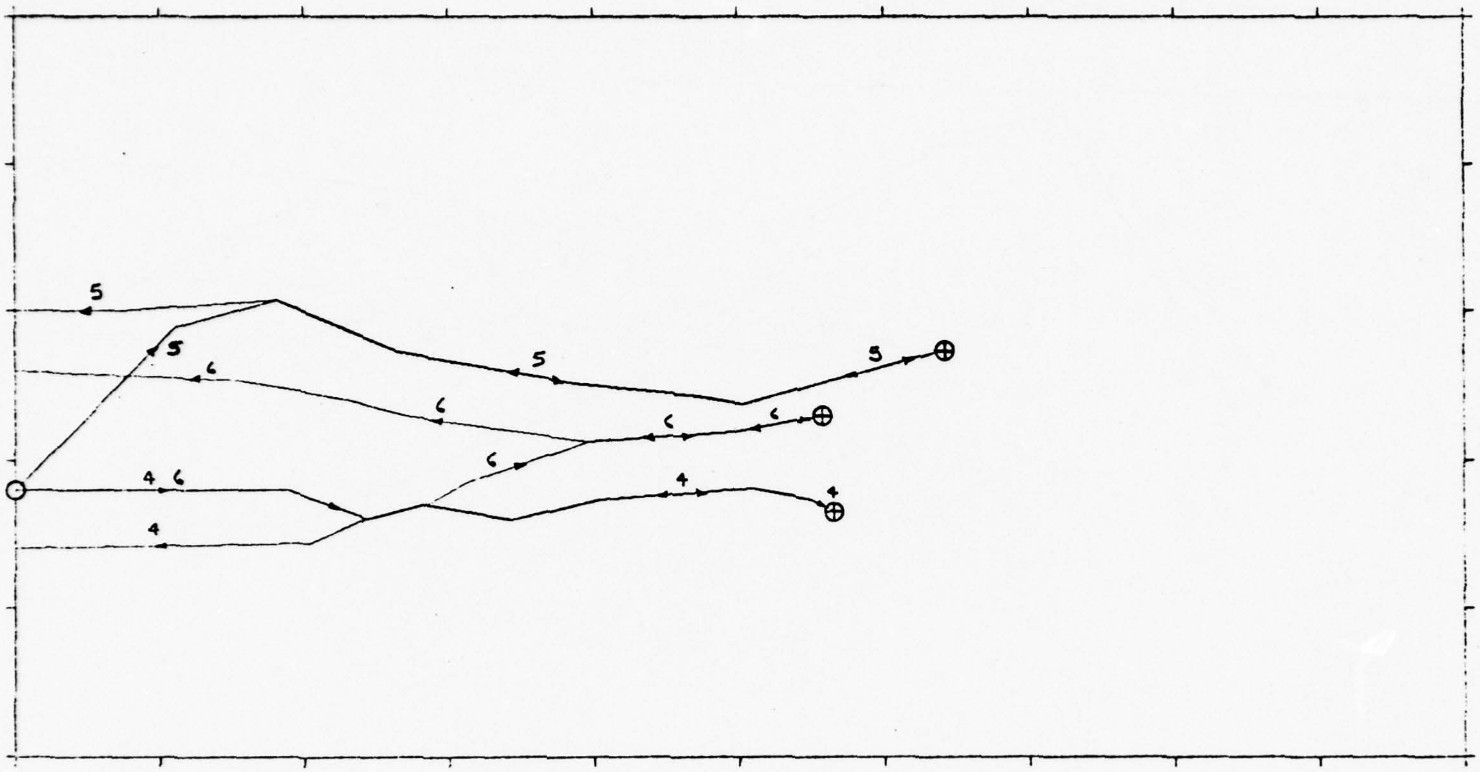
*Use one column only. Enter: M my route preferred; C computer route preferred.

**Enter rating of "non-preferred" route.



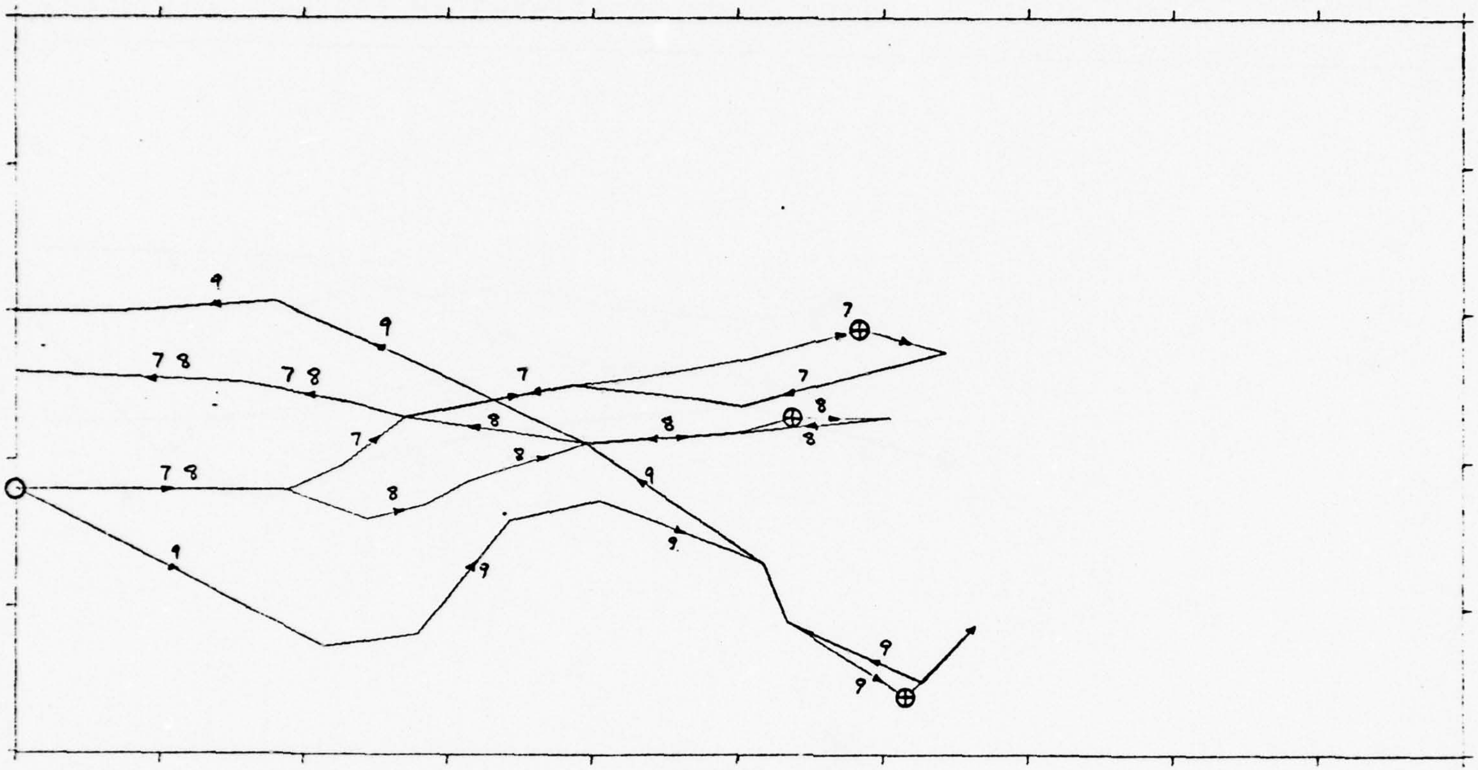
SS MAP B ROUTE 1 ALTERNATIVES (RUNNING FIRE)

Original size of map: 7.5 x 14.5 inches



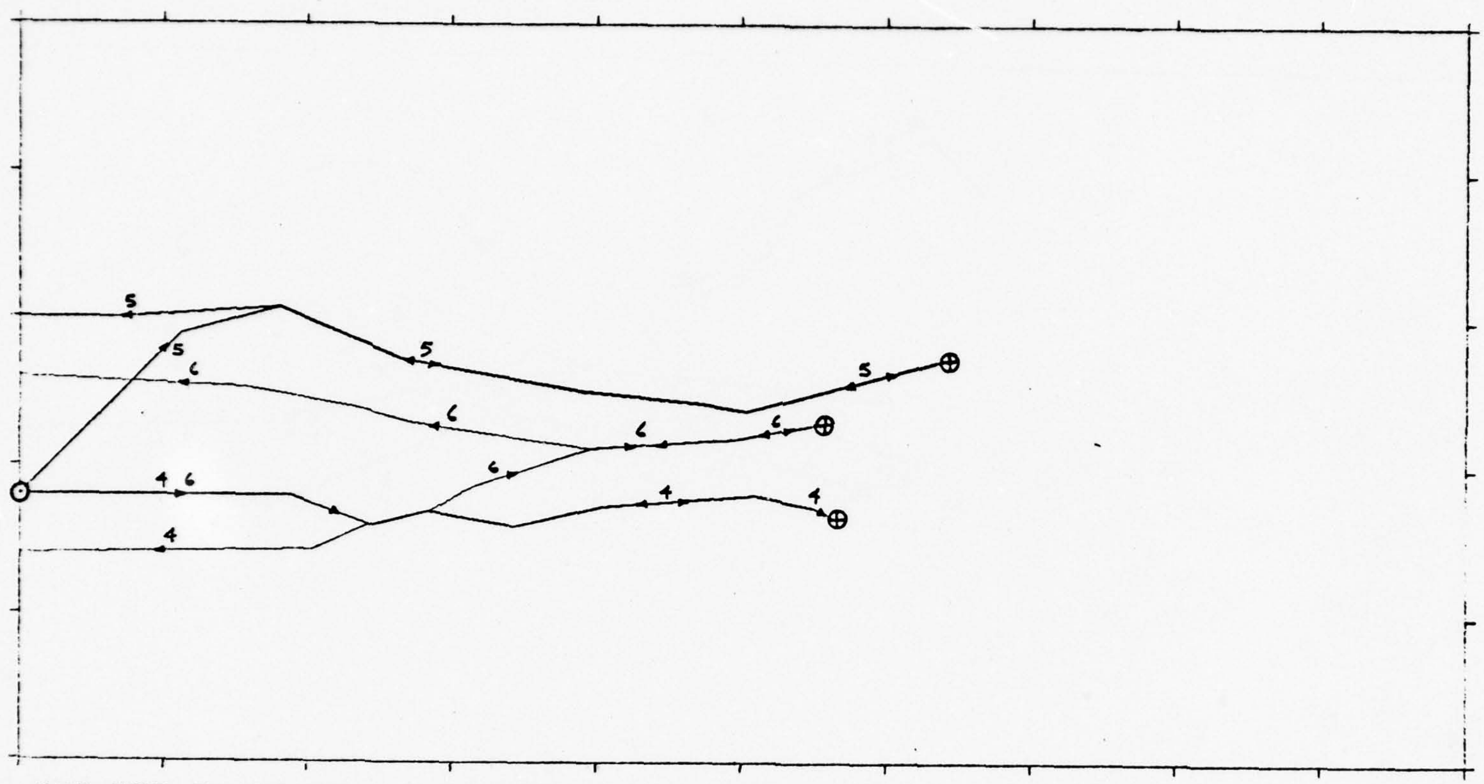
SS MAP B ROUTE 1 ALTERNATIVES (HOVER FIRE)

Original size of map: 7.5 x 14.5 inches



SUBJECT 7 ROUTE 1 ALTERNATIVES (RUNNING FIRE)

Original size of map: 7.5 x 14.5 inches



SUBJECT 7 ROUTE 1 ALTERNATIVES (HOVER FIRE)

Original size of map: 7.5 x 14.5 inches

Exhibit D. 16

Summary Text of Session Plan Item B. 3. a

Instructions for Transferring Routes

The package I have just handed you contains a variety of materials that will be used during the remainder of this morning's session. You will notice that among these materials are the four acetate route overlays that you prepared for me during our first session. Also, there are four map sheets that correspond to the tactical situations that you faced in preparing each of the four route overlays. As you can see, these map sheets actually correspond to the map boards that you used during the first session.

The first item of business that we wish to accomplish this morning is to transfer the routes from the acetate overlays to the four map sheets I have provided. There are actually two reasons for this exercise. The first reason is that we wish to refamiliarize you with the routes that you picked and also with the situations that you faced. The second purpose of the exercise is to prepare a map board which has your route registered on it, and which may be used later in evaluating the route alternatives that have been prepared by the computer.

As you transfer each of your routes from your acetate overlays, I want you to be very careful in transfering the route to make sure that the map sheet that you use actually corresponds to the tactical situation that is associated with the particular route. Your route overlays and the map sheets are labeled so that you should be able to do this with no difficulty. However, I will monitor your progress to make sure that there are no problems. Please let me know if you have any questions.

Exhibit D. 17

Summary Text of Session Plan Item B. 4. a

Instructions for Using Route Overlays and Answer
Sheets in Performing Route Evaluations

Now that we have the map sheets with the routes recorded on them, I want you to take a look at the other materials I have provided in your package. First, you will find there are four translucent plots, or overlays, that have been prepared by the computer for each of your four routes. Furthermore, on each of these translucent overlays you will find plots of three alternative routes. During the remainder of the session this morning, we are going to be comparing the alternative routes that appear on these translucent overlays with the routes that you have just traced on the situation map sheets. Each of the overlays is labeled so that you will be able to identify it with a particular route that you chose during our first session.

Now, let us take our first route map sheet and the four computer overlays associated with it. You will notice if you lay the first overlay over your map sheet you will be able to do a comparison between the route you picked and the three alternative routes that appear on the overlay. The procedure will be to prepare some information about your feelings with regard to the three alternatives that appear on this first overlay. You will then select the second overlay for route 1 followed by the third overlay for route 1. Then you will progress to your route 2 and repeat the process. The procedure will continue until all four of your routes have been analyzed.

Now, I have also included four answer sheets in the package; one answer sheet for each route and its alternatives. On this answer sheet you will record the data that I am going to explain. What we want you to do is to compare each alternative to the route which you selected, giving us your own subjective evaluation of the alternative with respect to the route you picked. For this purpose the answer sheet indicates that we are going to allow you to classify an alternative in any one of four categories.

The first category is the one in which you feel that there is absolutely no difference between the alternative and the route you picked. In this situation you would have to, for example, toss a coin to decide whether you would use the route you picked or the particular alternative.

The second category we have labeled as being almost indifferent. Actually, such a label is bad terminology. What we really mean is that should an alternative fall in this category you would be unable to cite any particular reason for the alternative being preferred to your route or vice versa, but at the same time you would still feel that one route is preferred over the other.

The last two categories are included for those situations in which you can definitely cite some reason for a preference to exist, either a preference for your route or a preference for the alternative route. Whether an alternative falls into the third category or the fourth category is strictly a matter of degree. You would classify those situations in which you mildly prefer one route to another in the third category. In the fourth category you would record those situations in which you strongly prefer one route to the other. We presume that a

route comparison would fall in the fourth category, if, for example, the computer alternative flagrantly violated some particular criterion that you use when you pick a route.

Once a particular route comparison has been made between your route and one of the alternatives, and once you have entered its qualitative evaluation on the answer sheet, we want you to actually rate the "non-preferred" route on a scale between zero and one hundred to indicate to us the degree of feeling that you have about the comparison that you have made. This scale has been divided into four regions for you to use in your evaluation, with each region being associated with a particular qualitative evaluation.

The first region is the one that includes routes that are definitely the same to you. A route alternative which you feel is definitely the same would be rated at one hundred. Next, for situations in which you are almost indifferent, you will select a value between ninety-five and ninety-nine to indicate your degree of preference. The number you select is the rating of the non-preferred route. For example, were you to feel that a route is almost as good as your own route, you might rate the computer route at ninety-seven. Consequently, you would use the second column of the answer sheet to indicate that you are almost indifferent, entering an "M" to indicate that you actually prefer your own route. Then, in column five, you would enter the rating that applies to the non-preferred route, in this case ninety-seven.

If you mildly prefer one route to another,you rate the non-preferred route in column five with a number between seventy and ninety-four. And, in

the third column of the answer sheet, you enter "M" if you prefer your own route or "C" if you prefer the computer route. Similarly, if you strongly prefer one route to another you rate the non-preferred route in column five with a number between zero and sixty-nine. Then you enter an "M" or a "C" in column four to indicate which route is preferred.

Now, in examining the translucent route overlays, you will notice that each alternative is labeled with a number. This same number appears on the answer sheets, and you will note that there can be as many as twelve alternatives. However, you may not find twelve alternatives for each route. The reason for this is that the computer sometimes duplicates routes. If such duplication exists, you will find that the same alternative number appears for each of the duplicate routes. So, all you have to do is perform the number of comparisons indicated on your answer sheets. In general, this number will be between eight and ten.

Next, you will notice that each alternative is labeled with sufficient arrow heads to indicate direction of motion at all points along the route. You will also notice that the firing point in each route is labeled with a red circle. Finally, you will notice that half of the alternatives are hover fire alternatives and half of the alternatives are running fire alternatives. We prepared both types of alternatives without regard to type of fire you selected during our original session. We want you to rate all of these alternatives, taking into consideration the factors you used in selecting one type of fire or another.

As you enter your answers on the answer sheet you are providing us both with quantitative and with qualitative information. However, there is additional qualitative information that you can provide which may be extremely valuable to us. If you feel so disposed, we would like you to actually tell us with comments, why you prefer one route over another. This information may be especially valuable for those situations in which you mildly prefer or strongly prefer your original route to one of the computer alternatives or vice versa. These qualitative statements may be of use in isolating particular facets of the route selection problem in which the computer model does not do a good job. We could then use the information to revise the route selection model to do a better job.

Remember, there are no right or wrong answers to the questions we are asking. We want you to give us your own personal reactions. You will never be judged in this experiment on the basis of your piloting capabilities. We strictly want information that reveals to us how helicopter pilots think.

You may start with your evaluations now and you may continue until you are finished. If there are any questions, I will be available to answer them.

APPENDIX E

PHASE II EXPERIMENTAL DATA AND ANALYSES

In this appendix the following abbreviations apply:

Threat Perception Model

AT	-	Acid Test Model
1	-	Model One
3	-	Model Three

Attack Mode

HF	-	Hover Fire
RF	-	Running Fire

Data Set

1	-	Results produced by using personalistic data from each subject
2	-	Results produced by using averaged or "super subject" data for each subject

Table E.1

Alternative Numbering Scheme

		Personal Data						Super Subject Data					
		AT		1		3		AT		1		3	
Subject	Route	RF	HF	RF	HF	RF	HF	RF	HF	RF	HF	RF	HF
6	1	1	4	2	5	3	4	1	4	2	5	3	4
	2	7	8	3	6	2	5	1	4	3	6	2	5
	3	7	9	3	6	8	10	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5
7	1	7	4	9	5	8	6	1	4	3	5	2	6
	2	7	9	3	6	8	10	1	4	3	6	2	5
	3	7	10	9	6	8	11	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5
8	1	1	3	2	5	1	3	1	3	2	4	1	3
	2	2	8	3	9	7	5	1	4	3	6	2	5
	3	7	8	3	6	7	9	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5
9	1	7	9	3	6	8	10	1	4	3	6	2	5
	2	7	10	9	6	8	11	1	4	3	6	2	5
	3	7	9	3	6	8	10	1	4	3	6	2	5
	4	7	8	3	6	7	9	1	4	3	6	2	5
10	1	6	8	2	5	7	4	1	4	2	5	3	4
	2	7	9	3	6	8	10	1	4	3	6	2	5
	3	7	9	3	6	8	10	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5
11	1	1	4	3	5	7	6	1	4	3	5	2	6
	2	1	5	3	6	7	5	1	4	3	6	2	5
	3	7	9	3	6	8	10	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5
12	1	1	3	2	5	1	3	1	3	2	4	1	3
	2	7	5	3	8	7	5	1	4	3	6	2	5
	3	7	9	3	6	8	10	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5
13	1	7	9	3	6	8	10	1	4	3	6	2	5
	2	7	9	3	6	8	10	1	4	3	6	2	5
	3	7	9	3	6	8	10	1	4	3	6	2	5
	4	7	9	3	6	8	10	1	4	3	6	2	5

Table E. 2

Summary of Similarity in Routes Produced by Two Data Sets

		AT		1		3		%	Totals
Subject	Route	RF	HF	RF	HF	RF	HF	Similarity	(%)
6	1	1	1	1	1	1	1	100	
	2	0	0	1	1	1	1	67	
	3	0	0	1	1	0	0	33	
	4	0	0	1	1	0	0	33	58
7	1	0	1	0	1	0	1	50	
	2	0	0	1	1	0	0	33	
	3	0	0	0	1	0	0	17	
	4	0	0	1	1	0	0	33	33
8	1	1	1	1	0	1	1	83	
	2	0	0	1	0	0	1	33	
	3	0	0	1	1	0	0	33	
	4	0	0	1	1	0	0	33	46
11	1	1	1	1	1	0	1	83	
	2	1	0	1	1	0	1	67	
	3	0	0	1	1	0	0	33	
	4	0	0	1	1	0	0	33	54
12	1	1	1	1	0	1	1	83	
	2	0	0	1	0	0	1	33	
	3	0	0	1	1	0	0	33	
	4	0	0	1	1	0	0	33	46
13	1	0	0	1	1	0	0	33	
	2	0	0	1	1	0	0	33	
	3	0	0	1	1	0	0	33	
	4	0	0	1	1	0	0	33	33
Totals (%)		21	21	92	83	17	38		45

1 - route produced by data set 1 is the same as that produced by data set 2

0 - different routes are produced

Table E. 3

Summary of Similarity in Routes Produced by Acid Test Model and Model Three

		Data Set 1		%	Totals	Data Set 2		%	Totals
Subject	Route	RF	HF	Similarity	(%)	RF	HF	Similarity	(%)
6	1	0	1	50		0	1	50	
	2	0	0	0		0	0	0	
	3	0	0	0		0	0	0	
	4	0	0	0	12	0	0	0	12
7	1	0	0	0		0	0	0	
	2	0	0	0		0	0	0	
	3	0	0	0		0	0	0	
	4	0	0	0	0	0	0	0	0
8	1	1	1	100		1	1	100	
	2	0	0	0		0	0	0	
	3	1	0	50		0	0	0	
	4	0	0	0	38	0	0	0	25
11	1	0	0	0		0	0	0	
	2	0	1	50		0	0	0	
	3	0	0	0		0	0	0	
	4	0	0	0	12	0	0	0	0
12	1	1	1	100		1	1	100	
	2	1	1	100		0	0	0	
	3	0	0	0		0	0	0	
	4	0	0	0	50	0	0	0	25
13	1	0	0	0		0	0	0	
	2	0	0	0		0	0	0	
	3	0	0	0		0	0	0	
	4	0	0	0	0	0	0	0	0
Totals (%)		17	21		19	8	12		10

1 - route produced by Acid Test Model is the same as that produced by Model Three

0 - different routes are produced

Table E.4

Summary of Similarity in Route Alternatives Presented to Comparable Subjects (Data Set 1)

Subject Pair	Route	First Subject Alternatives						Second Subject Alternatives						% Similarity
		1	2	3	4	5	6	1	2	3	4	5	6	
(7, 11)	1	1	1	0	1	0	1	0	1	0	1	1	1	67
	2	1	0	1	1	0	0	0	0	1	1	1	0	50
	3	0	0	1	1	0	0	0	0	1	1	0	0	33
	4	0	0	1	1	0	0	0	0	1	1	0	0	33
(8, 12)	1	1	1	1	1	1	1	1	1	1	1	1	1	100
	2	0	0	1	1	1	1	1	1	1	1	1	1	83
	3	0	0	1	1	0	0	0	0	1	1	0	0	33
	4	0	0	1	1	0	0	0	0	1	1	0	0	33
Total for (7, 11) (%)														46
Total for (8, 12) (%)														62
Overall														54

1 - at least one route alternative of paired subject is the same as the alternative in question

0 - no comparable route alternative exists for paired subject

Table E. 5

Alternative Route Ratings

		Personal Data						Super Subject Data					
		AT		1		3		AT		1		3	
Subject	Route	RF	HF	RF	HF	RF	HF	RF	HF	RF	HF	RF	HF
6	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0. 60	0. 60	0	0	0	0	0. 60	0. 60	0	0
	3	0. 60	0. 40	0. 75	0. 60	0. 78	0. 30	0. 60	0. 10	0. 75	0. 76	0. 65	0. 75
	4	1. 33	1. 33	1. 06	0. 69	1. 33	0. 40	0. 85	0. 50	1. 06	0. 69	0. 70	1. 08
7	1	1. 00	1. 11	1. 00	0. 70	1. 00	1. 05	0. 50	1. 11	0. 95	0. 70	0. 50	1. 05
	2	0. 50	0. 50	1. 00	1. 00	0. 50	0. 75	0. 40	0. 40	1. 00	1. 00	0. 40	0. 40
	3	0. 95	0. 95	1. 00	1. 00	0. 95	1. 00	0. 98	0. 95	1. 00	1. 00	0. 75	0. 90
	4	1. 05	0. 90	1. 05	1. 05	1. 05	1. 05	1. 25	1. 05	1. 05	1. 05	0. 50	0. 75
8	1	0. 40	0. 20	1. 00	0. 96	0. 40	0. 20	0. 40	0. 20	1. 00	1. 00	0. 40	0. 20
	2	0. 85	0. 75	1. 03	1. 04	0. 75	0. 75	0. 85	0. 80	1. 03	1. 03	0. 85	0. 75
	3	0. 97	0. 98	0. 98	1. 00	0. 97	0. 98	0. 71	0. 73	0. 98	1. 00	0. 96	0. 85
	4	0. 97	1. 00	1. 00	1. 00	0. 97	1. 00	0. 72	0. 40	1. 00	1. 00	0. 96	0. 95
11	1	0. 75	0. 70	0. 97	0. 20	0. 15	0. 95	0. 75	0. 70	0. 97	0. 20	0. 70	0. 95
	2	0. 10	0. 40	1. 04	1. 05	0. 70	0. 40	0. 10	0. 10	1. 04	1. 05	0. 10	0. 40
	3	0. 98	0. 90	0. 98	1. 00	0. 98	0. 73	0. 75	0. 90	0. 98	1. 00	0. 70	0. 77
	4	0. 70	0. 75	0. 99	1. 05	0. 50	0. 50	0. 95	0. 95	0. 99	1. 05	0. 05	0. 72
12	1	0. 97	0. 69	0. 79	0. 06	0. 97	0. 69	0. 97	0. 69	0. 79	0. 60	0. 97	0. 69
	2	0. 98	0. 70	0. 90	0. 05	0. 98	0. 70	0. 60	0. 70	0. 90	0. 80	0. 60	0. 70
	3	0. 90	0. 94	0	0	0. 90	0. 94	0. 80	0. 30	0	0	0. 80	0. 10
	4	0. 93	0. 80	0	0	0. 93	0. 80	0. 60	0. 90	0	0	0. 60	0. 90
13	1	0. 05	0	0. 55	0. 25	0. 55	0. 90	0. 50	0. 25	0. 55	0. 25	0. 90	0. 70
	2	0	0	0	0. 05	0. 55	0. 90	0. 55	0. 05	0	0. 05	0. 90	0. 90
	3	0	0. 95	1. 00	0	0. 80	0. 80	0. 99	0. 80	1. 00	0	0. 99	0. 99
	4	0	0. 99	0	0. 79	0. 90	0. 90	0. 95	0. 80	0	0. 79	0. 95	0. 75

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	243.00	243.00	$\sigma_e^2 + 24\,\sigma_1^2$	
2-Route	3	60090.92	20030.30	$\sigma_e^2 + 12\,\sigma_2^2$	***
3-Perception Model	2	3552.88	1776.44	$\sigma_e^2 + 16\,\sigma_3^2$	***
4-Attack Mode	1	1704.08	1704.08	$\sigma_e^2 + 24\,\sigma_4^2$	**
12	3	1107.00	369.00	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	1478.62	739.31	$\sigma_e^2 + 8\,\sigma_{13}^2$	*
14	1	408.33	408.33	$\sigma_e^2 + 12\,\sigma_{14}^2$	
23	6	8220.96	1370.16	$\sigma_e^2 + 4\,\sigma_{23}^2$	***
24	3	1777.59	592.53	$\sigma_e^2 + 6\,\sigma_{24}^2$	*
34	2	9.54	4.77	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	7905.92	256.78	σ_e^2	
Total	47	86499.00			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E.1.--Analysis of Variance for Subject 6

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	2508.52	2508.52	$\sigma_e^2 + 24\,\sigma_1^2$	***
2-Route	3	8229.73	2743.24	$\sigma_e^2 + 12\,\sigma_2^2$	***
3-Perception Model	2	4876.04	2438.02	$\sigma_e^2 + 16\,\sigma_3^2$	***
4-Attack Mode	1	1.69	1.69	$\sigma_e^2 + 24\,\sigma_4^2$	
12	3	1614.73	538.24	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	3563.30	1781.65	$\sigma_e^2 + 8\,\sigma_{13}^2$	***
14	1	1.02	1.02	$\sigma_e^2 + 12\,\sigma_{14}^2$	
23	6	5486.96	914.49	$\sigma_e^2 + 4\,\sigma_{23}^2$	**
24	3	126.90	42.30	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	315.88	157.94	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	5845.66	254.16	σ_e^2	
Total	47	32570.40			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E.2.--Analysis of Variance for Subject 7

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	396.75	396.75	$\sigma_e^2 + 24\,\sigma_1^2$	**
2-Route	3	12801.14	4267.04	$\sigma_e^2 + 12\,\sigma_2^2$	***
3-Perception Model	2	9193.02	4596.51	$\sigma_e^2 + 16\,\sigma_3^2$	***
4-Attack Mode	1	396.75	396.75	$\sigma_e^2 + 24\,\sigma_4^2$	**
12	3	663.11	221.04	$\sigma_e^2 + 6\,\sigma_{12}^2$	**
13	2	682.65	341.32	$\sigma_e^2 + 8\,\sigma_{13}^2$	***
14	1	56.33	56.33	$\sigma_e^2 + 12\,\sigma_{14}^2$	
23	6	6691.51	1115.25	$\sigma_e^2 + 4\,\sigma_{23}^2$	***
24	3	300.78	100.26	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	223.65	111.83	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	1339.94	58.26	σ_e^2	
Total	47	32745.61			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.3.--Analysis of Variance for Subject 8

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	75.00	75.00	$\sigma_e^2 + 24\,\sigma_1^2$	
2-Route	3	7925.42	2641.81	$\sigma_e^2 + 12\,\sigma_2^2$	***
3-Perception Model	2	9522.16	4761.07	$\sigma_e^2 + 16\,\sigma_3^2$	***
4-Attack Mode	1	52.08	52.08	$\sigma_e^2 + 24\,\sigma_4^2$	
12	3	1076.50	358.83	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	98.01	49.01	$\sigma_e^2 + 8\,\sigma_{13}^2$	
14	1	176.33	176.33	$\sigma_e^2 + 12\,\sigma_{14}^2$	
23	6	14946.35	2491.06	$\sigma_e^2 + 4\,\sigma_{23}^2$	***
24	3	915.42	305.14	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	2650.18	1325.09	$\sigma_e^2 + 8\,\sigma_{34}^2$	*
Residual	23	11348.40	493.41	σ_e^2	
Total	47	48785.83			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.4.--Analysis of Variance for Subject 11

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	540.02	540.02	$\sigma_e^2 + 24\,\sigma_1^2$	
2-Route	3	6246.90	2082.30	$\sigma_e^2 + 12\,\sigma_2^2$	***
3-Perception Model	2	23325.08	11662.54	$\sigma_e^2 + 16\,\sigma_3^2$	***
4-Attack Mode	1	3553.51	3553.51	$\sigma_e^2 + 24\,\sigma_4^2$	***
12	3	2231.40	743.80	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	3140.74	1570.37	$\sigma_e^2 + 8\,\sigma_{13}^2$	**
14	1	553.53	553.53	$\sigma_e^2 + 12\,\sigma_{14}^2$	
23	6	9681.25	1613.54	$\sigma_e^2 + 4\,\sigma_{23}^2$	***
24	3	2486.25	828.75	$\sigma_e^2 + 6\,\sigma_{24}^2$	*
34	2	240.74	120.37	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	7698.01	334.70	σ_e^2	
Total	47	59697.40			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.5.--Analysis of Variance for Subject 12

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	2821.32	2821.32	$\sigma_e^2 + 24\,\sigma_1^2$	*
2-Route	3	10505.74	3501.91	$\sigma_e^2 + 12\,\sigma_2^2$	**
3-Perception Model	2	23004.05	11502.03	$\sigma_e^2 + 16\,\sigma_3^2$	***
4-Attack Mode	1	6.75	6.75	$\sigma_e^2 + 24\,\sigma_4^2$	
12	3	136.20	45.40	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	2815.25	1407.62	$\sigma_e^2 + 8\,\sigma_{13}^2$	
14	1	3468.01	3468.01	$\sigma_e^2 + 12\,\sigma_{14}^2$	*
23	6	5628.62	938.10	$\sigma_e^2 + 4\,\sigma_{23}^2$	
24	3	5852.43	1950.81	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	978.60	489.30	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	20074.72	872.81	σ_e^2	
Total	47	75291.62			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.6.--Analysis of Variance for Subject 13

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	36510.46	12170.15	$\sigma_e^2 + 6\,\sigma_1^2$	***
2-Perception Model	2	1396.75	698.38	$\sigma_e^2 + 8\,\sigma_2^2$	
3-Attack Mode	1	1890.38	1890.38	$\sigma_e^2 + 12\,\sigma_3^2$	**
12	6	6561.92	1093.65	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	3	2074.46	691.49	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	982.75	491.38	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	1525.92	254.32	σ_e^2	
Total	23	50942.62			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.7.--Analysis of Variance for Subject 6
Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1 - Route	3	3723.46	1241.15	$\sigma_e^2 + 6\,\sigma_1^2$	***
2 - Perception Model	2	441.75	220.88	$\sigma_e^2 + 8\,\sigma_2^2$	
3 - Attack Mode	1	0.04	0.04	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	2856.92	476.15	$\sigma_e^2 + 2\,\sigma_{12}^2$	**
13	3	178.46	59.49	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	267.58	133.79	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	514.42	85.74	σ_e^2	
Total	23	7982.62			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E. 8 .--Analysis of Variance for Subject 7
Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	8444.79	2814.93	$\sigma_e^2 + 6\,\sigma_1^2$	***
2-Perception Model	2	3142.58	1571.29	$\sigma_e^2 + 8\,\sigma_2^2$	***
3-Attack Mode	1	77.04	77.04	$\sigma_e^2 + 12\,\sigma_3^2$	*
12	6	3955.09	659.18	$\sigma_e^2 + 2\,\sigma_{12}^2$	***
13	3	267.80	89.27	$\sigma_e^2 + 3\,\sigma_{13}^2$	**
23	2	39.58	19.79	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	86.04	14.34	σ_e^2	
Total	23	16012.90			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.9 .--Analysis of Variance for Subject 8
Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	3898.79	1299.60	$\sigma_e^2 + 6\,\sigma_1^2$	
2-Perception Model	2	4064.08	2032.04	$\sigma_e^2 + 8\,\sigma_2^2$	
3-Attack Mode	1	18.38	18.38	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	5632.59	938.76	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	3	162.79	54.26	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	698.25	349.12	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	6575.04	1095.84	σ_e^2	
Total	23	21049.91			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E.10.--Analysis of Variance for Subject 11
Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	804.83	268.28	$\sigma_e^2 + 6\sigma_1^2$	
2-Perception Model	2	21760.07	10880.03	$\sigma_e^2 + 8\sigma_2^2$	***
3-Attack Mode	1	3456.00	3456.00	$\sigma_e^2 + 12\sigma_3^2$	***
12	6	3464.93	577.49	$\sigma_e^2 + 2\sigma_{12}^2$	*
13	3	2754.33	918.11	$\sigma_e^2 + 3\sigma_{13}^2$	**
23	2	720.77	360.38	$\sigma_e^2 + 4\sigma_{23}^2$	
Residual	6	1098.86	183.14	σ_e^2	
Total	23	34059.79			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E. 11.--Analysis of Variance for Subject 12 Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	5154.46	1718.15	$\sigma_e^2 + 6\,\sigma_1^2$	
2-Perception Model	2	13497.58	6748.79	$\sigma_e^2 + 8\,\sigma_2^2$	*
3-Attack Mode	1	1890.37	1890.37	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	2354.42	392.40	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	3	3661.13	1220.38	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	3451.76	1725.88	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	10230.20	1705.03	σ_e^2	
Total	23	40239.91			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E. 12.--Analysis of Variance for Subject 13
Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1 - Route	3	24687.46	8229.15	$\sigma_e^2 + 6\,\sigma_1^2$	***
2 - Perception Model	2	3634.75	1817.38	$\sigma_e^2 + 8\,\sigma_2^2$	**
3- Attack Mode	1	222.04	222.04	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	3671.92	611.99	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	3	224.13	74.71	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	1131.08	565.54	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	1742.25	290.38	σ_e^2	
Total	23	35313.62			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E. 13.--Analysis of Variance for Subject 6
Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	6121.00	2040.33	$\sigma_e^2 + 6\,\sigma_1^2$	*
2-Perception Model	2	7997.58	3998.79	$\sigma_e^2 + 8\,\sigma_2^2$	**
3-Attack Mode	1	2.67	2.67	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	4145.75	690.96	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	3	39.01	13.00	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	259.09	129.54	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	3514.21	585.70	σ_e^2	
Total	23	22079.29			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.14.--Analysis of Variance for Subject 7
Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	5019.46	1673.15	$\sigma_e^2 + 6\,\sigma_1^2$	***
2-Perception Model	2	6733.08	3366.54	$\sigma_e^2 + 8\,\sigma_2^2$	***
3-Attack Mode	1	376.04	376.04	$\sigma_e^2 + 12\,\sigma_3^2$	**
12	6	3543.92	590.65	$\sigma_e^2 + 2\,\sigma_{12}^2$	***
13	3	117.79	39.26	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	223.09	111.54	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	322.54	53.76	σ	
Total	23	16335.91			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E. 15.--Analysis of Variance for Subject 8 Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	5103.12	1701.04	$\sigma_e^2 + 6\,\sigma_1^2$	***
2-Perception Model	2	5556.08	2778.04	$\sigma_e^2 + 8\,\sigma_2^2$	**
3-Attack Mode	1	210.04	210.04	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	10860.25	1810.04	$\sigma_e^2 + 2\,\sigma_{12}^2$	**
13	3	1475.80	491.93	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	2460.59	1230.29	$\sigma_e^2 + 4\,\sigma_{23}^2$	*
Residual	6	1995.05	332.51	σ_e^2	
Total	23	27660.93			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.16.--Analysis of Variance for Subject 11
Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	7673.46	2557.82	$\sigma_e^2 + 6\,\sigma_1^2$	**
2-Perception Model	2	4705.75	2352.88	$\sigma_e^2 + 8\,\sigma_2^2$	**
3-Attack Mode	1	651.04	651.04	$\sigma_e^2 + 12\,\sigma_3^2$	
12	6	7003.92	1167.32	$\sigma_e^2 + 2\,\sigma_{12}^2$	*
13	3	3303.13	1101.04	$\sigma_e^2 + 3\,\sigma_{13}^2$	*
23	2	55.09	27.54	$\sigma_e^2 + 4\,\sigma_{23}^2$	
Residual	6	1705.25	284.21	σ_e^2	
Total	23	25097.62			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E. 17.--Analysis of Variance for Subject 12
Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	5487.46	1829.15	$\sigma_e^2 + 6\sigma_1^2$	
2-Perception Model	2	12321.75	6160.88	$\sigma_e^2 + 8\sigma_2^2$	**
3-Attack Mode	1	1584.38	1584.38	$\sigma_e^2 + 12\sigma_3^2$	
12	6	3582.92	597.15	$\sigma_e^2 + 2\sigma_{12}^2$	
13	3	2373.46	791.15	$\sigma_e^2 + 3\sigma_{13}^2$	
23	2	365.25	182.62	$\sigma_e^2 + 4\sigma_{23}^2$	
Residual	6	6515.42	1085.90	σ_e^2	
Total	23	32230.62			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E.18.--Analysis of Variance for Subject 13
Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	1725.51	1725.51	$\sigma_e^2 + 48\,\sigma_1^2 + 24\,\sigma_{13}^2$	
2-Route	3	15419.78	5139.93	$\sigma_e^2 + 24\,\sigma_2^2 + 12\,\sigma_{23}^2$	**
3-Subject	1	4280.01	4280.01	$\sigma_e^2 + 48\,\sigma_3^2$	***
4-Perception Model	2	13676.81	6838.41	$\sigma_e^2 + 32\,\sigma_4^2 + 16\,\sigma_{34}^2$	**
5-Attack Mode	1	36.26	36.26	$\sigma_e^2 + 48\,\sigma_5^2 + 24\,\sigma_{35}^2$	
12	3	473.87	157.96	$\sigma_e^2 + 12\,\sigma_{12}^2$	
13	1	858.01	858.01	$\sigma_e^2 + 24\,\sigma_{13}^2$	
14	2	2420.40	1210.20	$\sigma_e^2 + 16\,\sigma_{14}^2$	**
15	1	102.09	102.09	$\sigma_e^2 + 24\,\sigma_{15}^2$	
23	3	735.37	245.12	$\sigma_e^2 + 12\,\sigma_{23}^2$	
24	6	17734.19	2955.70	$\sigma_e^2 + 8\,\sigma_{24}^2$	***
25	3	611.62	203.87	$\sigma_e^2 + 12\,\sigma_{25}^2$	
34	2	721.40	360.70	$\sigma_e^2 + 16\,\sigma_{34}^2$	
35	1	17.52	17.52	$\sigma_e^2 + 24\,\sigma_{35}^2$	
45	2	2297.90	1148.95	$\sigma_e^2 + 16\,\sigma_{45}^2$	*
Residual	63	24524.69	389.28	σ_e^2	
Total	95	85635.12			

*Significant at $\alpha = 0.10$
**Significant at $\alpha = 0.05$
***Significant at $\alpha = 0.01$

Figure E. 19.--Analysis of Variance for Subjects 7 and 11

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Data Set	1	931.26	931.26	$\sigma_e^2 + 48\,\sigma_1^2 + 24\,\sigma_{13}^2$	***
2-Route	3	3174.61	1058.20	$\sigma_e^2 + 24\,\sigma_2^2 + 12\,\sigma_{23}^2$	
3-Subject	1	8990.01	8990.01	$\sigma_e^2 + 48\,\sigma_3^2$	***
4-Perception Model	2	1812.56	906.28	$\sigma_e^2 + 32\,\sigma_4^2 + 16\,\sigma_{34}^2$	
5-Attack Mode	1	3162.51	3162.51	$\sigma_e^2 + 48\,\sigma_5^2 + 24\,\sigma_{35}^2$	
12	3	2260.04	753.34	$\sigma_e^2 + 12\,\sigma_{12}^2$	**
13	1	5.51	5.51	$\sigma_e^2 + 24\,\sigma_{13}^2$	
14	2	2675.15	1337.57	$\sigma_e^2 + 16\,\sigma_{14}^2$	***
15	1	128.34	128.34	$\sigma_e^2 + 24\,\sigma_{15}^2$	
23	3	15873.45	5291.15	$\sigma_e^2 + 12\,\sigma_{23}^2$	***
24	6	12452.36	2075.39	$\sigma_e^2 + 8\,\sigma_{24}^2$	***
25	3	1847.62	615.87	$\sigma_e^2 + 12\,\sigma_{25}^2$	*
34	2	30705.65	15352.82	$\sigma_e^2 + 16\,\sigma_{34}^2$	***
35	1	787.77	787.77	$\sigma_e^2 + 24\,\sigma_{35}^2$	*
45	2	0.40	0.20	$\sigma_e^2 + 16\,\sigma_{45}^2$	
Residual	63	16624.96	263.89	σ_e^2	
Total	95	101431.75			

*Significant at $\alpha = 0.10$
**Significant at $\alpha = 0.05$
***Significant at $\alpha = 0.01$

Figure E.20.--Analysis of Variance for Subjects 8 and 12

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	5668.25	1889.42	$\sigma_e^2 + 12\,\sigma_1^2 + 6\,\sigma_{12}^2$	
2-Subject	1	4485.33	4485.33	$\sigma_e^2 + 24\,\sigma_2^2$	***
3-Perception Model	2	3337.17	1668.58	$\sigma_e^2 + 16\,\sigma_3^2 + 8\,\sigma_{23}^2$	
4-Attack Mode	1	8.33	8.33	$\sigma_e^2 + 24\,\sigma_4^2 + 12\,\sigma_{24}^2$	
12	3	1954.00	651.33	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	6	7543.50	1257.25	$\sigma_e^2 + 4\,\sigma_{13}^2$	**
14	3	127.00	42.33	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	1168.67	584.33	$\sigma_e^2 + 8\,\sigma_{23}^2$	
24	1	10.09	10.09	$\sigma_e^2 + 12\,\sigma_{24}^2$	
34	2	837.17	418.58	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	8378.36	364.28	σ_e^2	
Total	47	33517.85			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E.21.--Analysis of Variance for Subjects 7 and 11
Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	2899.73	966.58	$\sigma_e^2 + 12\,\sigma_1^2 + 6\,\sigma_{12}^2$	
2-Subject	1	4275.19	4275.18	$\sigma_e^2 + 24\,\sigma_2^2$	***
3-Perception Model	2	4190.17	2095.08	$\sigma_e^2 + 16\,\sigma_3^2 + 8\,\sigma_{23}^2$	
4-Attack Mode	1	2282.52	2282.52	$\sigma_e^2 + 24\,\sigma_4^2 + 12\,\sigma_{24}^2$	
12	3	6349.90	2116.63	$\sigma_e^2 + 6\,\sigma_{12}^2$	***
13	6	6676.83	1112.81	$\sigma_e^2 + 4\,\sigma_{13}^2$	***
14	3	2131.90	710.63	$\sigma_e^2 + 6\,\sigma_{14}^2$	***
23	2	20712.46	10356.23	$\sigma_e^2 + 8\,\sigma_{23}^2$	***
24	1	1250.51	1250.51	$\sigma_e^2 + 12\,\sigma_{24}^2$	***
34	2	225.17	112.58	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	3353.55	145.81	σ_e^2	
Total	47	54347.90			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E. 22.--Analysis of Variance for Subjects 8 and 12 Data Set 1

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	3	10225.40	3408.47	$\sigma_e^2 + 12\,\sigma_1^2 + 6\,\sigma_{12}^2$	***
2-Subject	1	652.69	652.69	$\sigma_e^2 + 24\,\sigma_2^2$	
3- Perception Model	2	12760.02	6380.01	$\sigma_e^2 + 16\,\sigma_3^2 + 8\,\sigma_{23}^2$	***
4-Attack Mode	1	130.02	130.02	$\sigma_e^2 + 24\,\sigma_4^2 + 12\,\sigma_{24}^2$	
12	3	998.73	332.91	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	6	11377.82	1896.30	$\sigma_e^2 + 4\,\sigma_{13}^2$	***
14	3	928.06	309.35	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	793.65	396.82	$\sigma_e^2 + 8\,\sigma_{23}^2$	
24	1	82.69	82.69	$\sigma_e^2 + 12\,\sigma_{24}^2$	
34	2	1515.57	757.78	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	10928.27	475.14	σ_e^2	
Total	47	50392.89			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure E. 23. --Analysis of Variance for Subjects 7 and 11 Data Set 2

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1 - Route	3	2534.92	844.97	$\sigma_e^2 + 12\,\sigma_1^2 + 6\,\sigma_{12}^2$	
2- Subject	1	4720.33	4720.33	$\sigma_e^2 + 24\,\sigma_2^2$	***
3- Perception Model	2	297.54	148.77	$\sigma_e^2 + 16\,\sigma_3^2 + 8\,\sigma_{23}^2$	
4- Attack Mode	1	1008.33	1008.33	$\sigma_e^2 + 24\,\sigma_4^2 + 12\,\sigma_{24}^2$	***
12	3	10158.00	3386.00	$\sigma_e^2 + 6\,\sigma_{12}^2$	***
13	6	6222.46	1037.08	$\sigma_e^2 + 4\,\sigma_{13}^2$	**
14	3	1500.67	500.22	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	11141.30	5570.64	$\sigma_e^2 + 8\,\sigma_{23}^2$	***
24	1	18.76	18.76	$\sigma_e^2 + 12\,\sigma_{24}^2$	
34	2	202.79	101.40	$\sigma_e^2 + 8\,\sigma_{34}^2$	
Residual	23	8348.77	362.99	σ_e^2	
Total	47	46153.84			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure E. 24.--Analysis of Variance for Subjects 8 and 12
Data Set 2

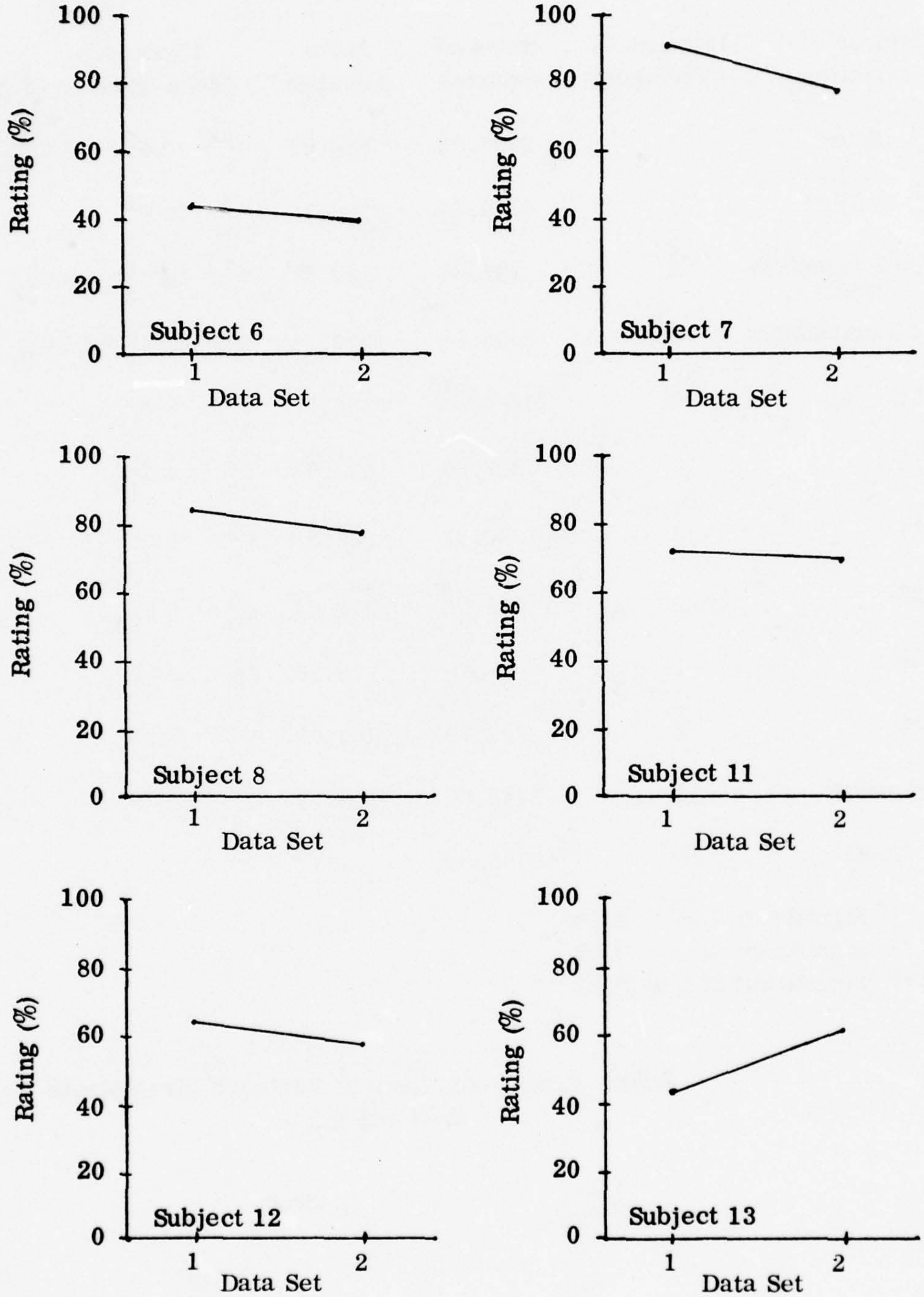


Figure E. 25. -- Plot of Data Set Effect by Subject

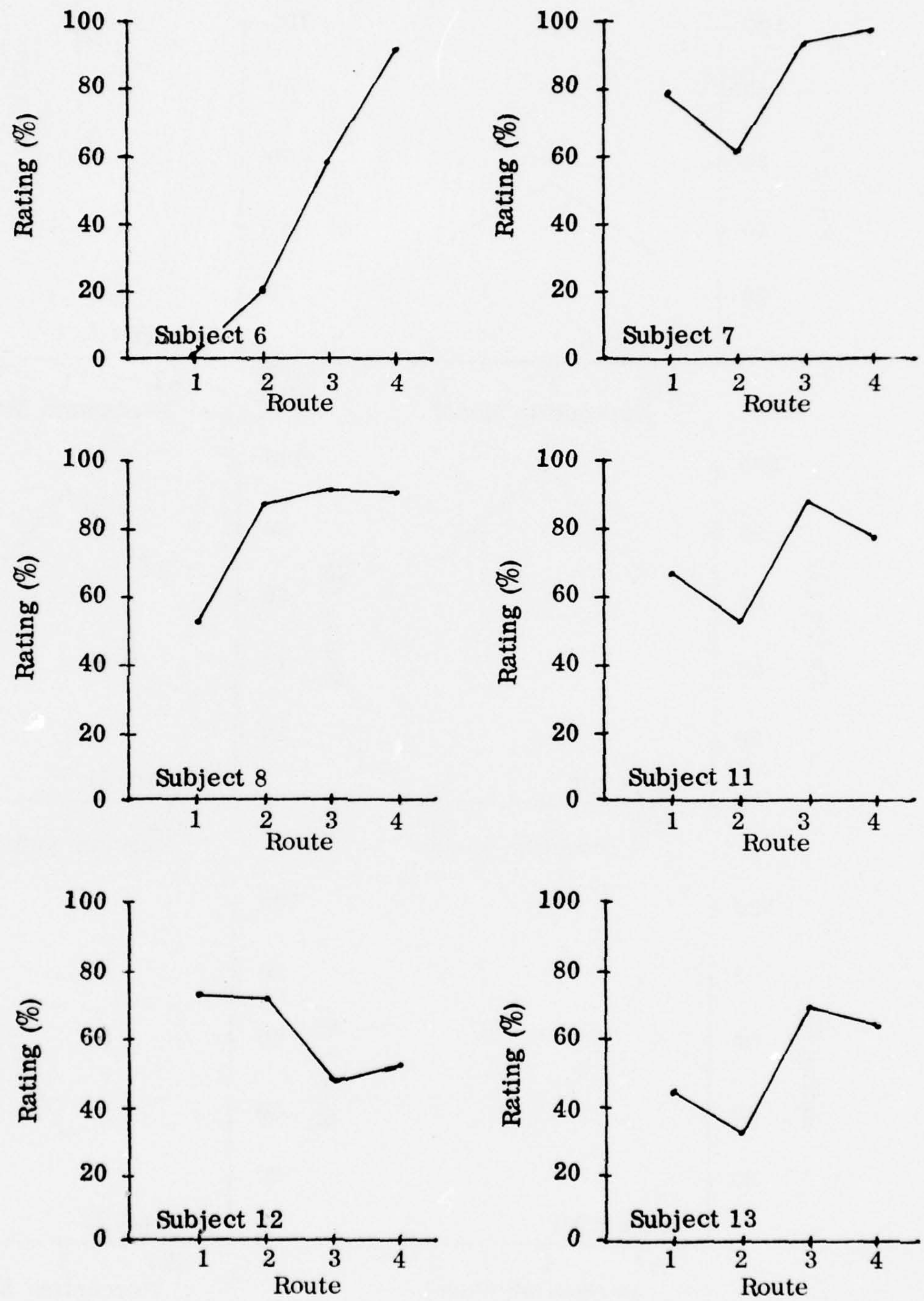


Figure E. 26. -- Plot of Route Effect by Subject
(Combined Data Sets)

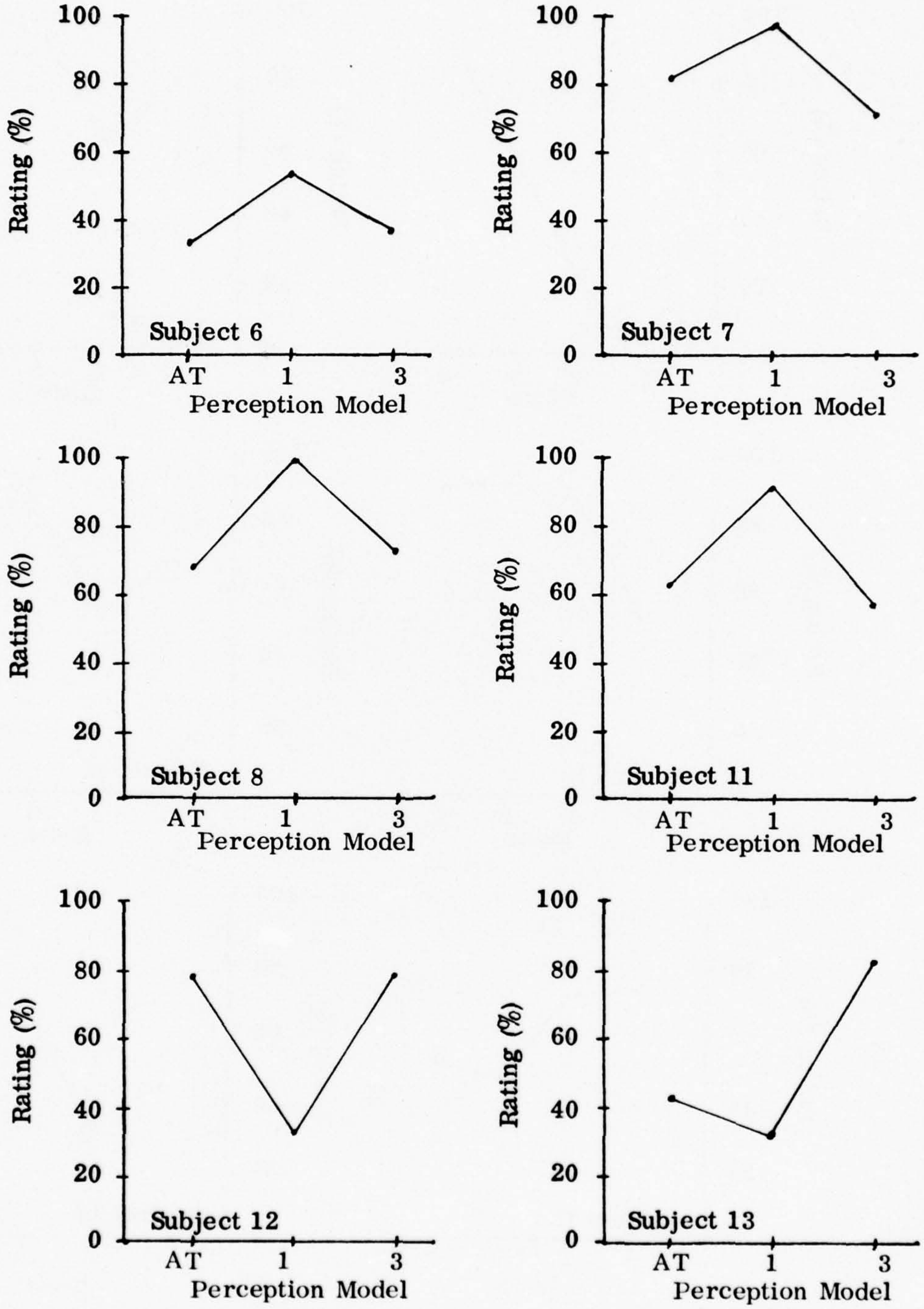


Figure E.27.--Plot of Perception Model Effect by Subject (Combined Data Sets)

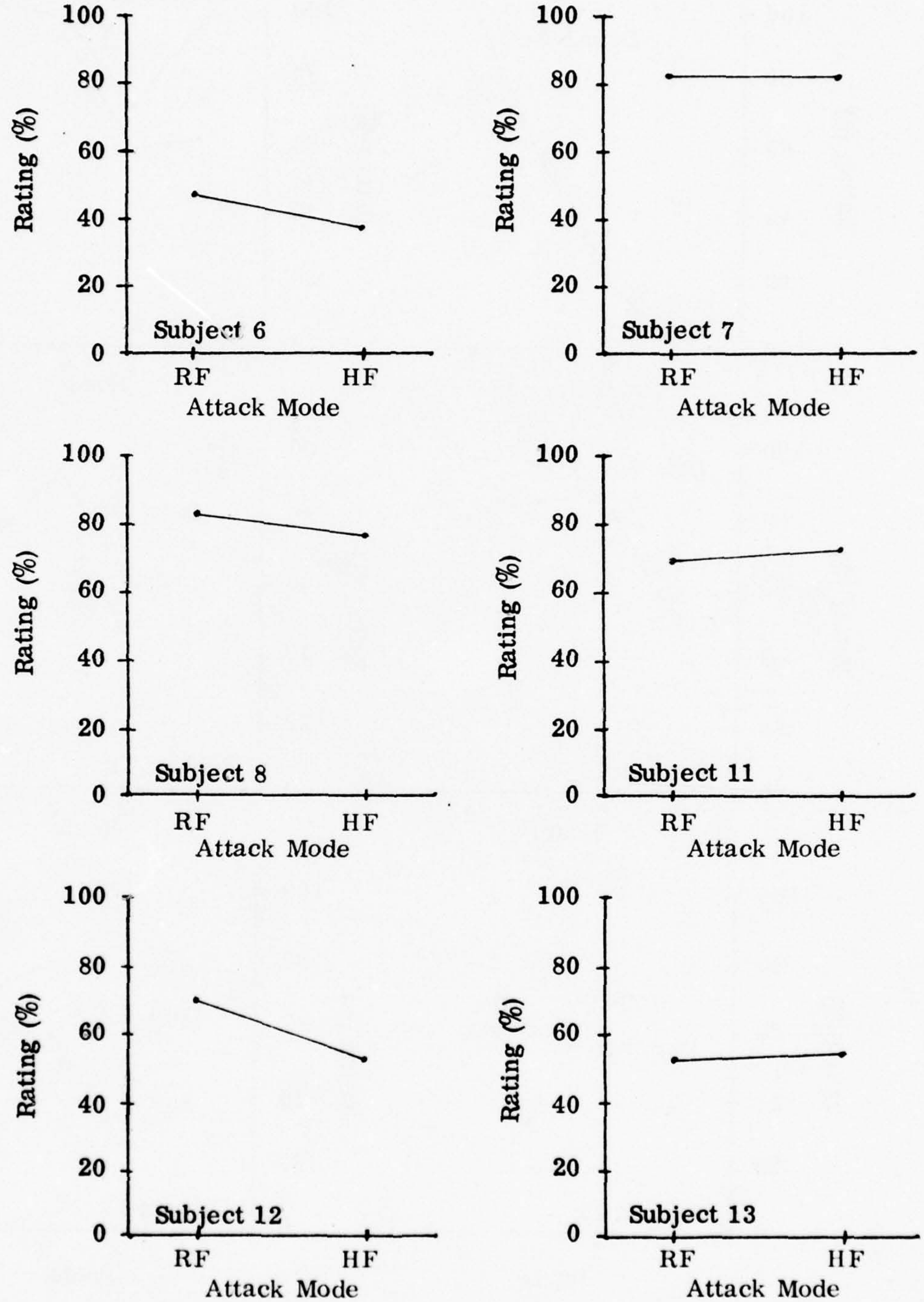


Figure E. 28.--Plot of Attack Mode Effect by Subject
(Combined Data Sets)

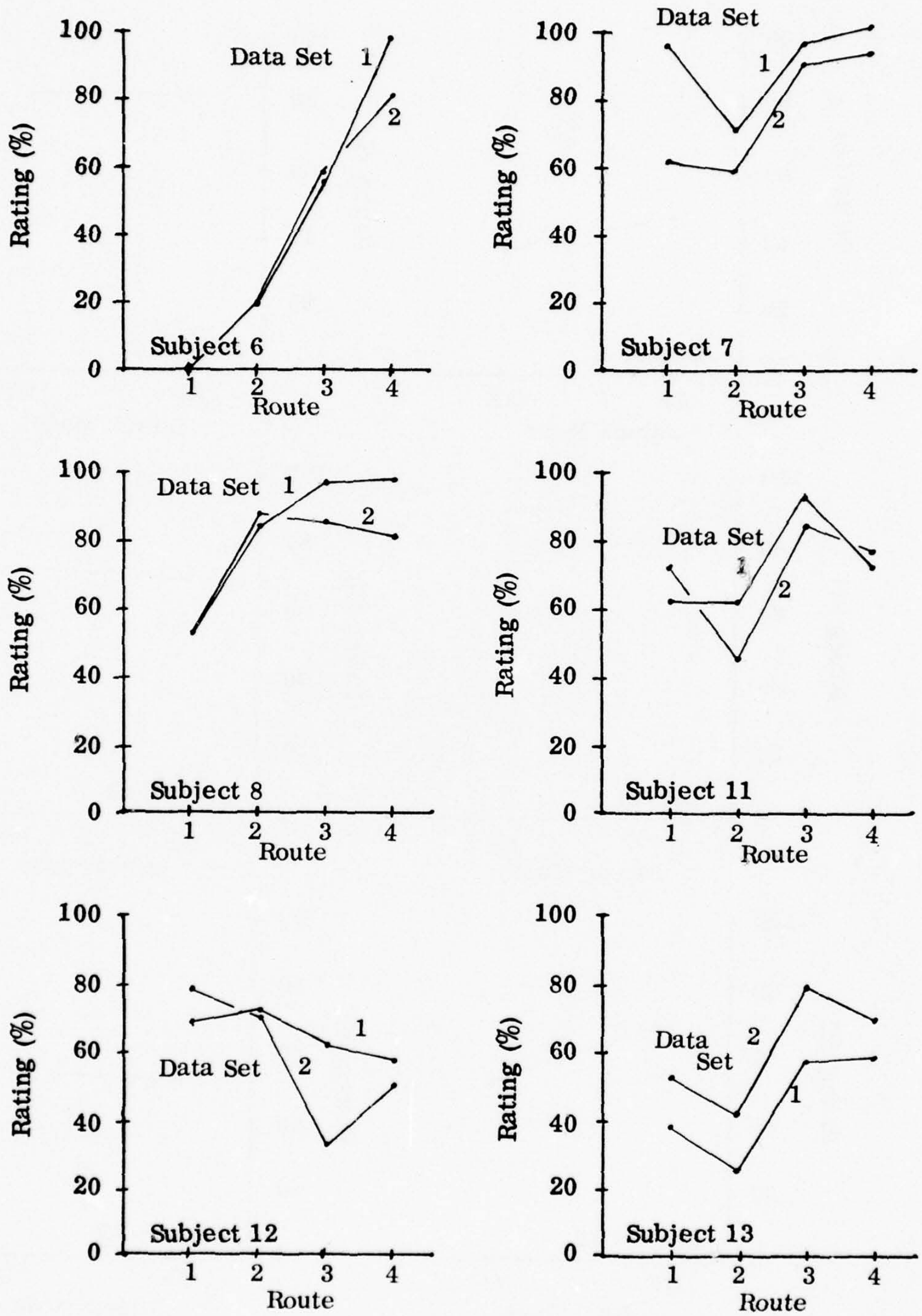


Figure E. 29.--Plot of Route Effect by Data Set and Subject

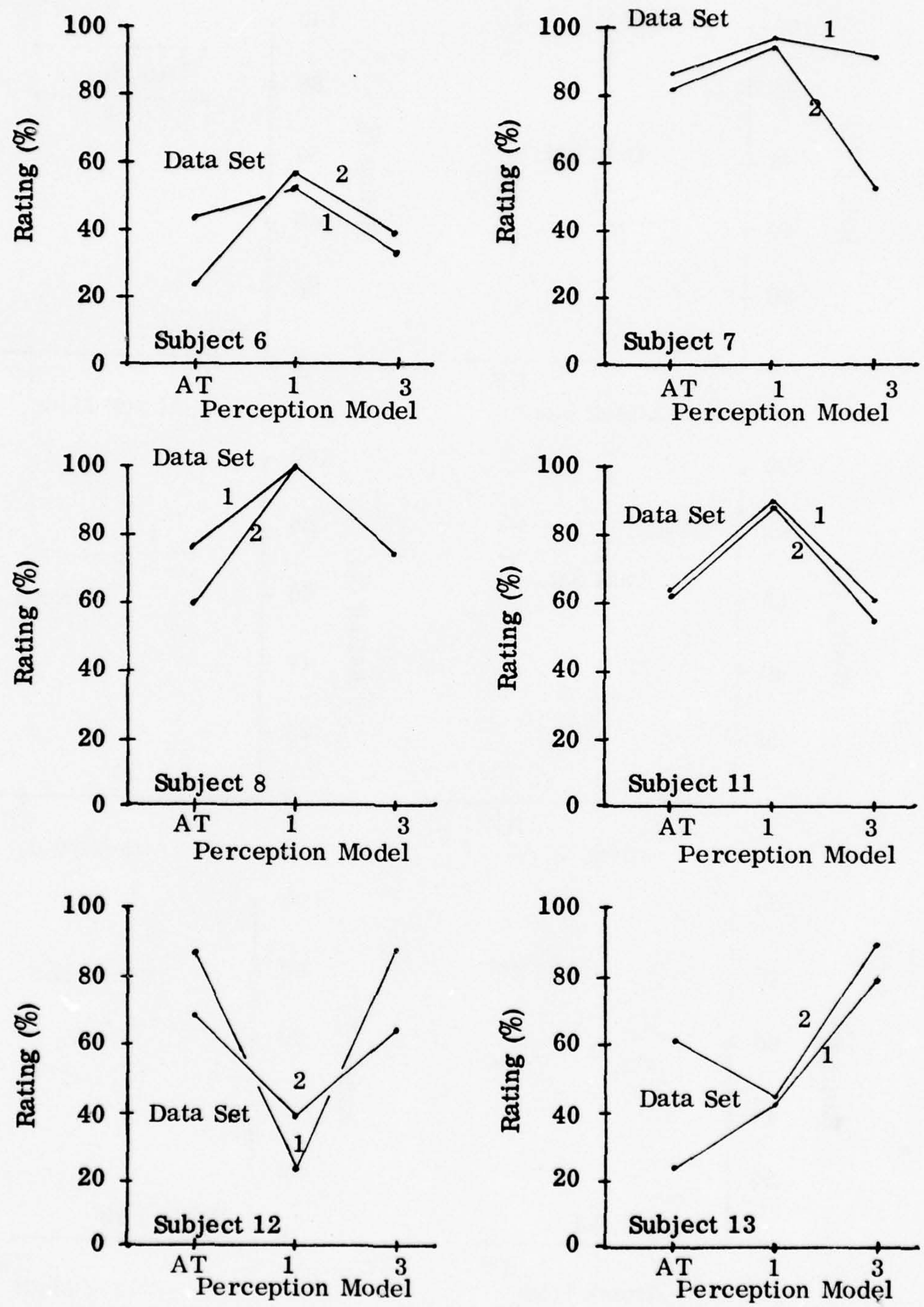


Figure E. 30. -- Plot of Perception Model Effect by Data Set and Subject

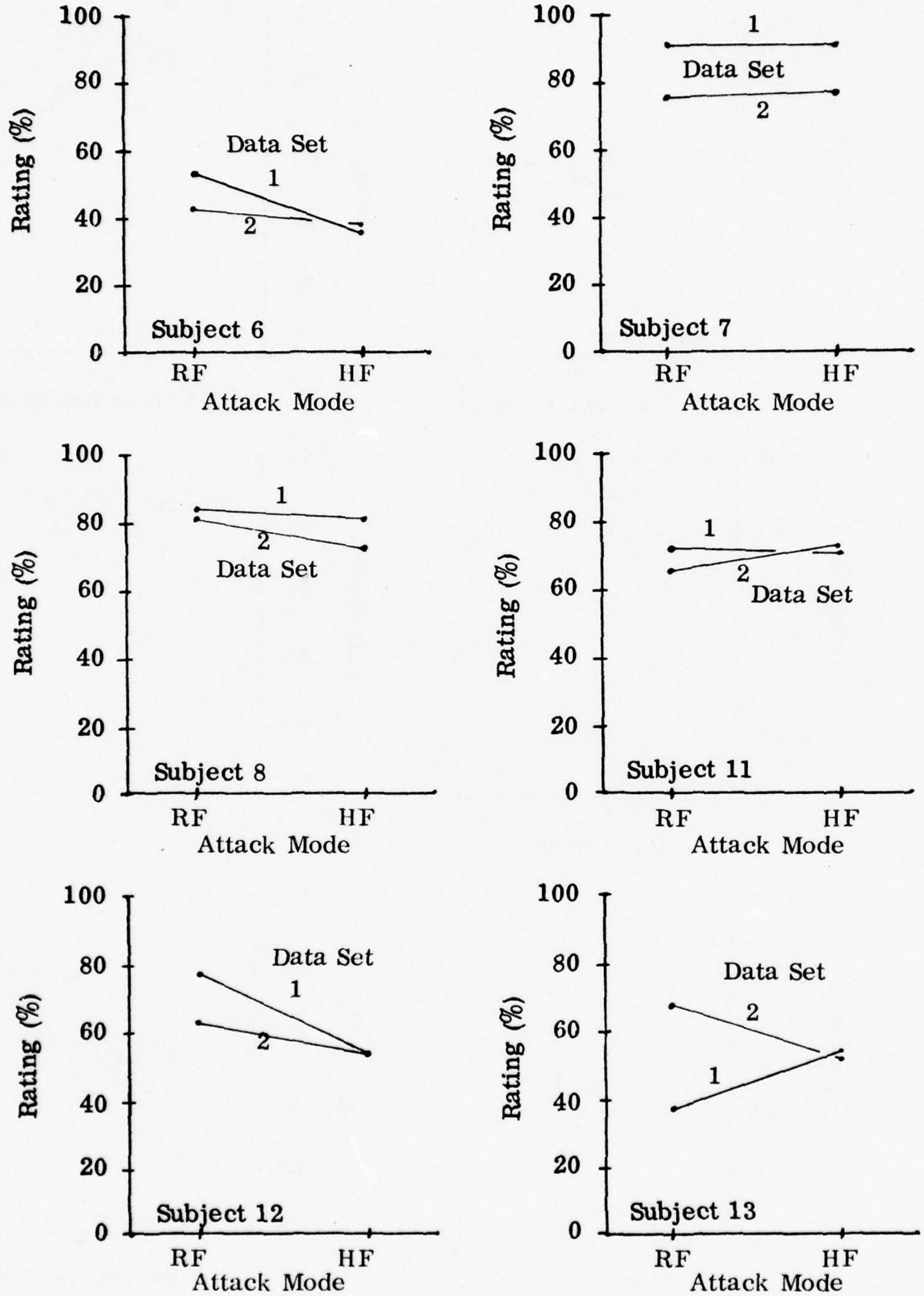


Figure E.31.--Plot of Attack Mode Effect by Data Set and Subject

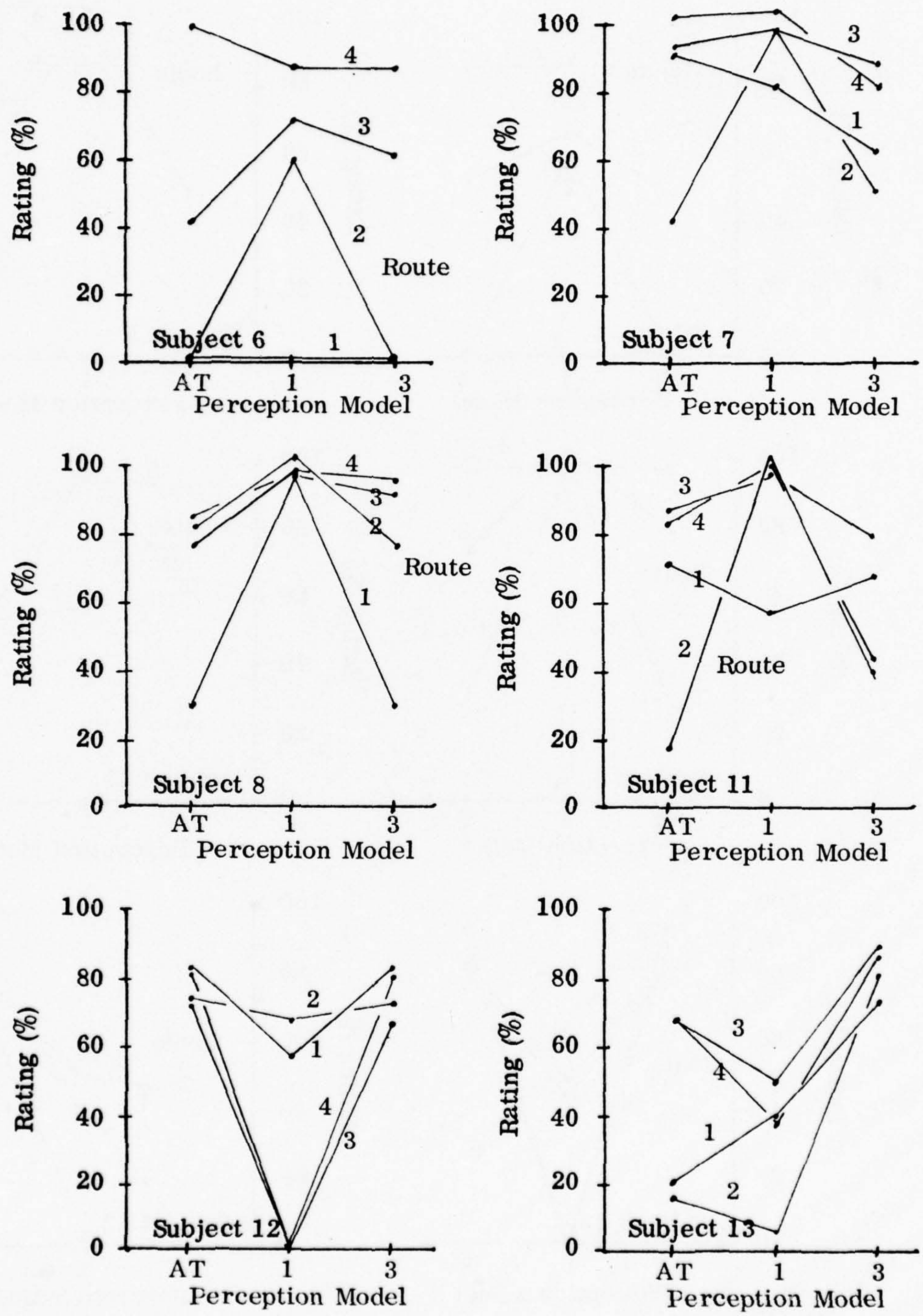


Figure E. 32.--Plot of Perception Model Effect by Route and Subject

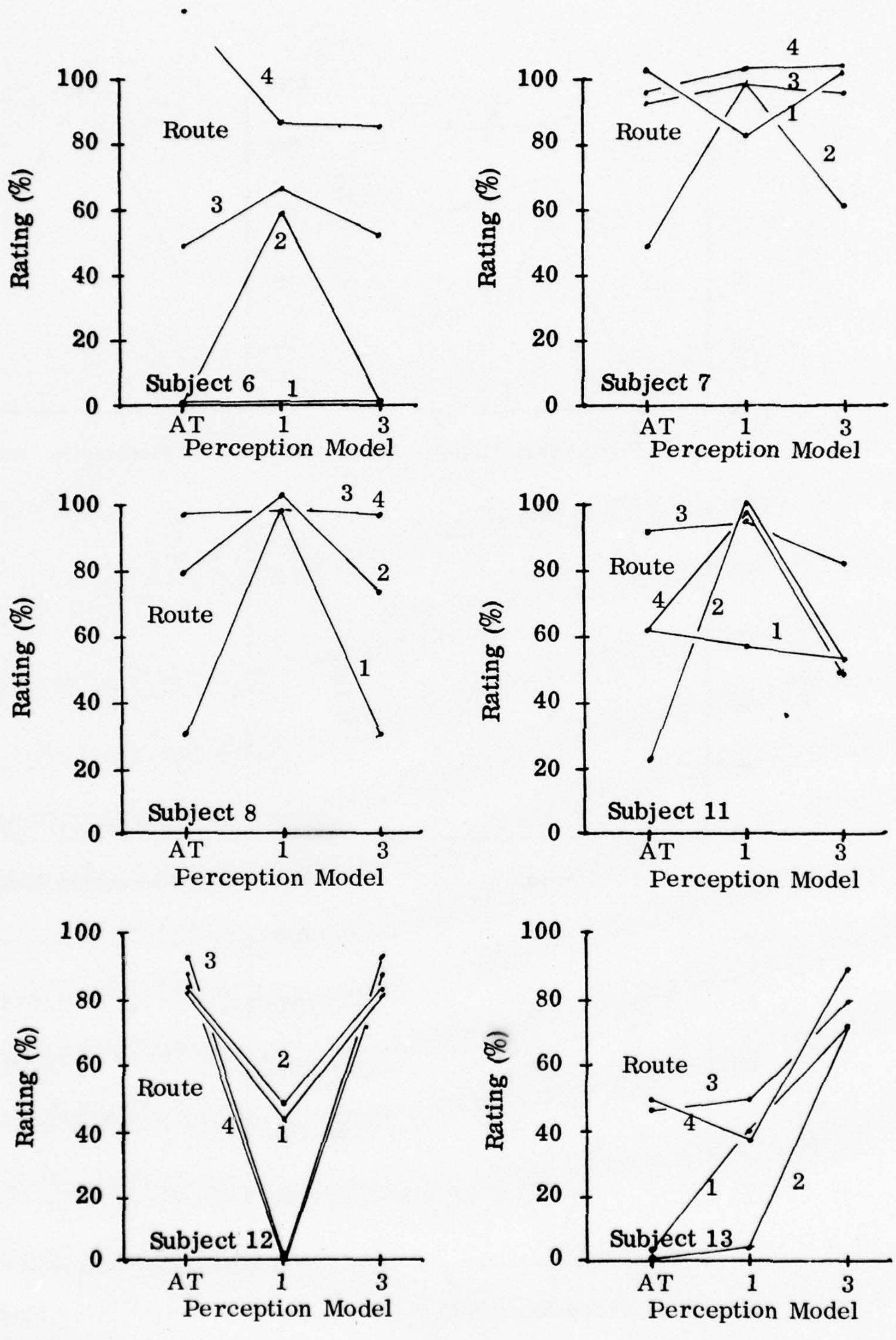


Figure E. 33. -- Plot of Perception Model Effect by Route and Subject (Data Set One)

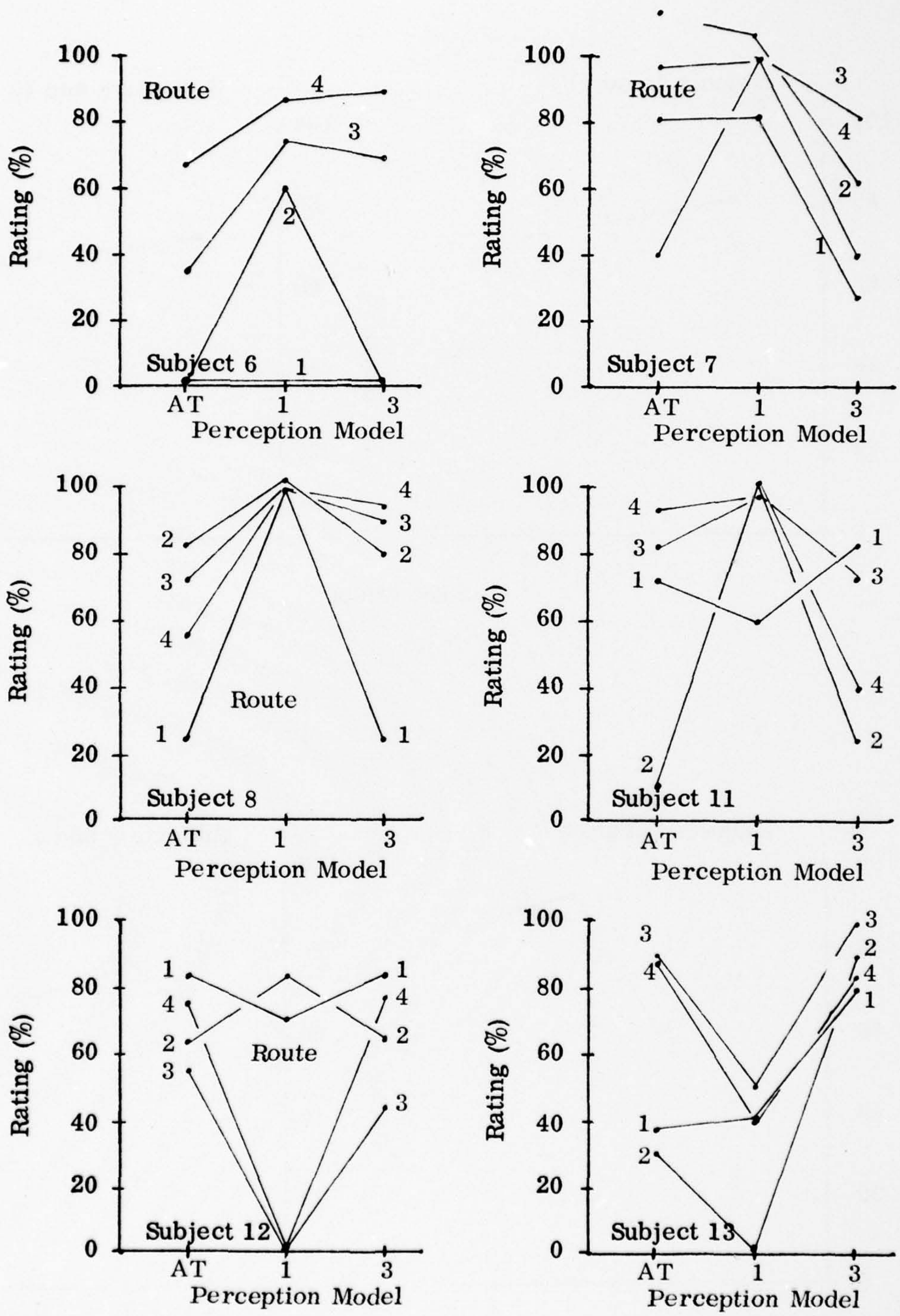


Figure E. 34.--Plot of Perception Model Effect by Route and Subject (Data Set Two)

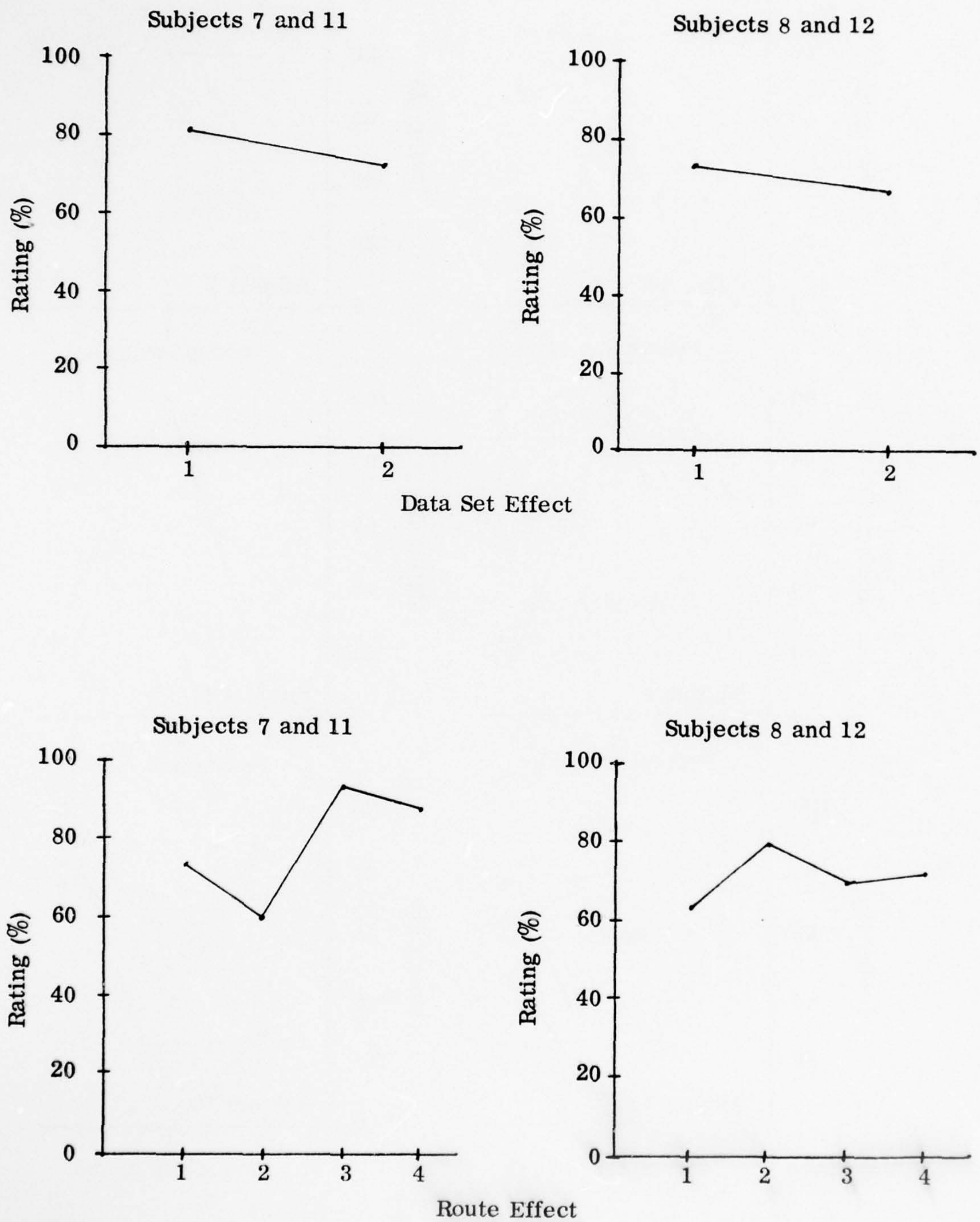


Figure E.35.--Plot of Main Effects by Subject Pair (Combined Data Sets)

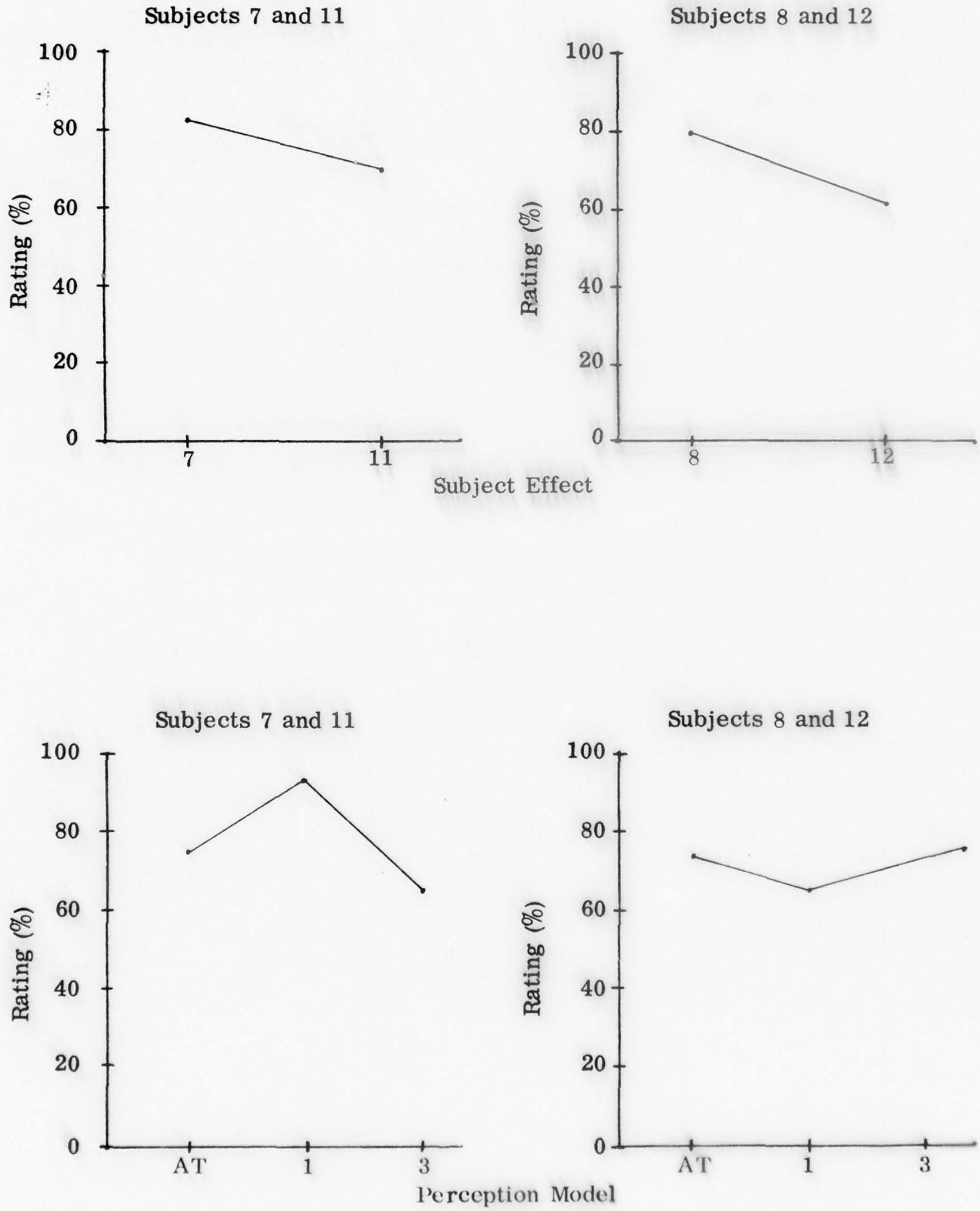


Figure E.36.--Plot of Main Effects by Subject Pair (Combined Data Sets)

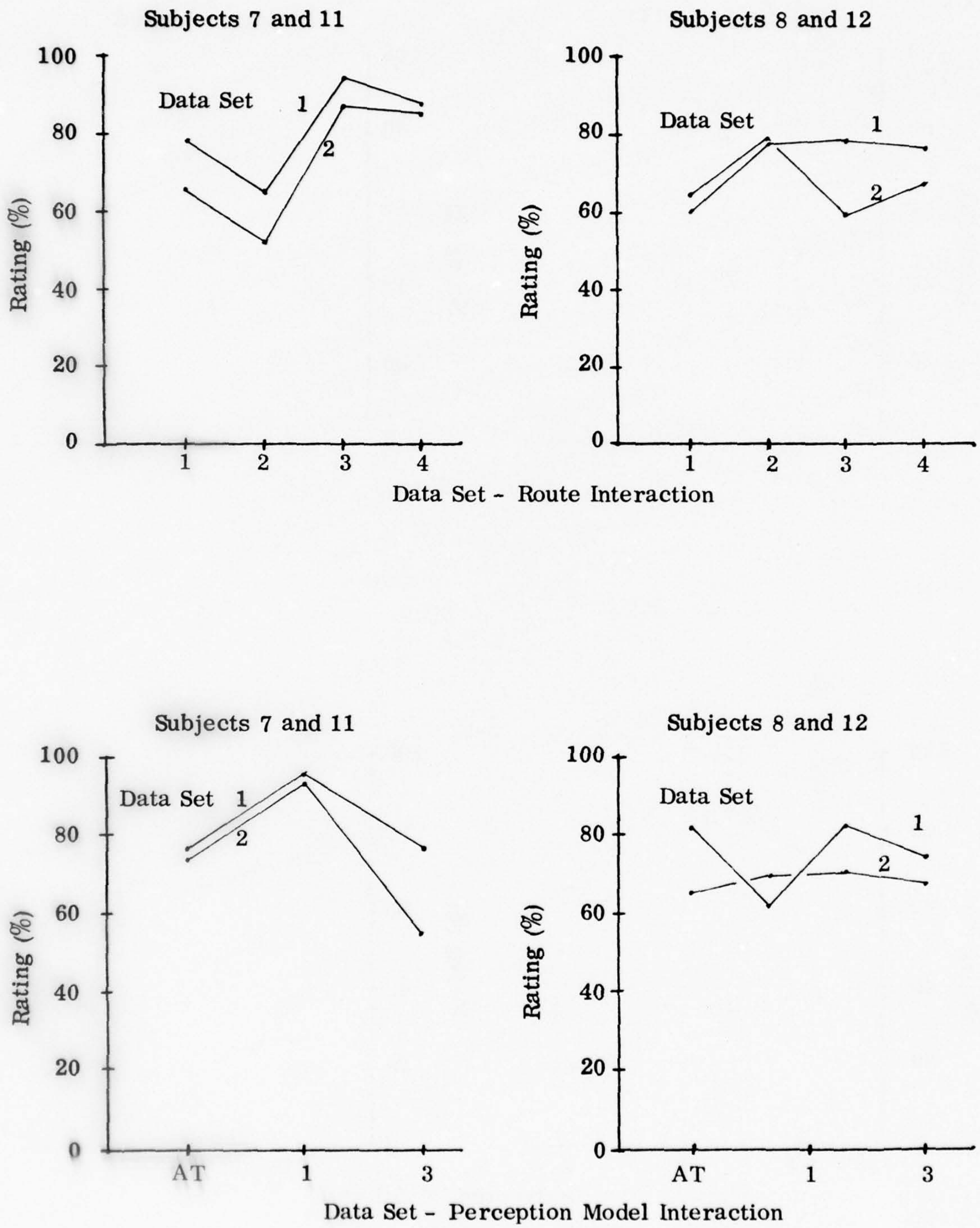


Figure E.37.--Plot of Interactions by Subject Pair (Combined Data Sets)

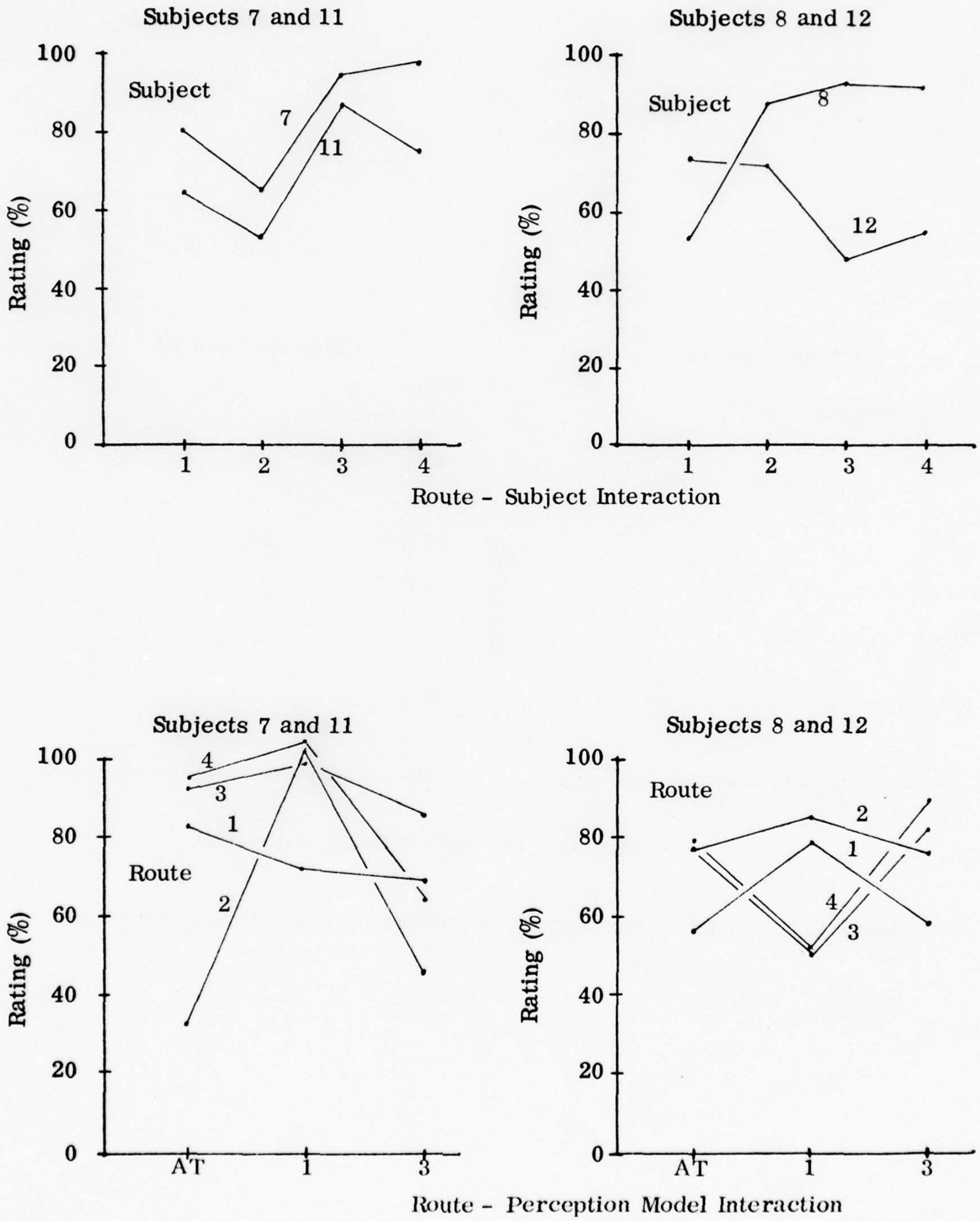


Figure E.38.--Plot of Interactions by Subject Pair (Combined Data Sets)

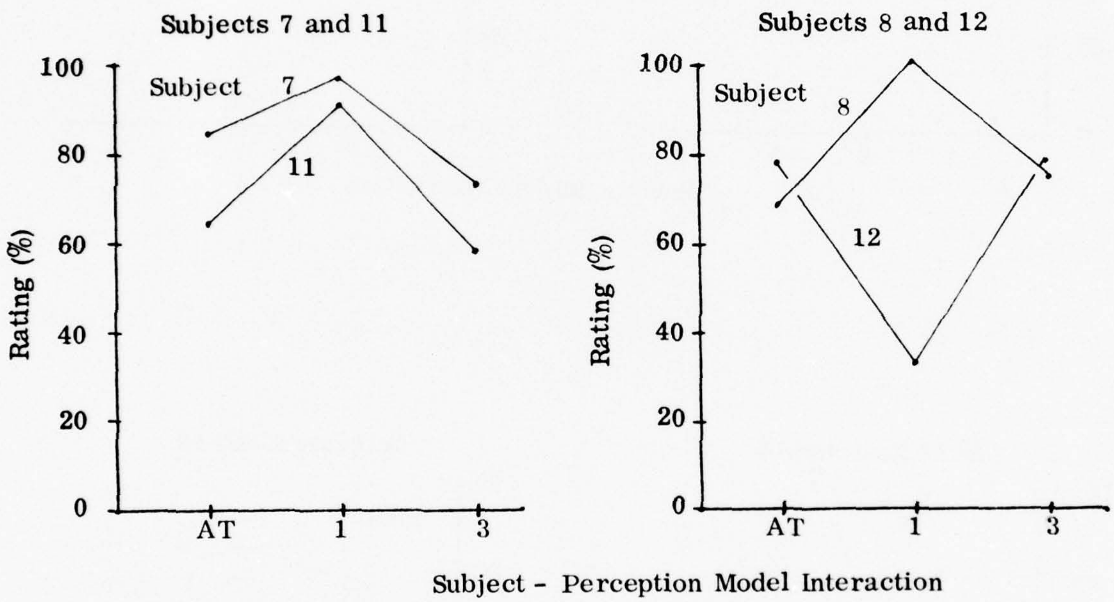


Figure E. 39.--Plot of Interactions by Subject Pair (Combined Data Sets)

APPENDIX F

TRIAL TWO EXPERIMENTAL DATA AND ANALYSES

In this appendix the following abbreviations apply:

Threat Perception Model

AT	-	Acid Test Model
1	-	Model One
3	-	Model Three

Attack Mode

HF	-	Hover Fire
RF	-	Running Fire

Exhibit F.1

Summary of Critique Responses

This exhibit presents summarized responses to questions comprising the critique administered at the end of the Phase I Experiment. Only seven out of eight subjects completed the critique.

Subject Number ______________

CRITIQUE

The questions on this form are intended to stimulate thought concerning the content of the experiment. Your ideas are solicited for the purpose of improving the experiment and for understanding better the responses you gave during the experiment. Please feel free to expand on your answers to any of the questions and to comment on any other topic that comes to mind. Use the additional paper provided if you need more space.

I. General

A. Was the intent of the experiment explained satisfactorily?

Yes - 7 No - 0	I would enjoy seeing the entire program in operation when it is complete - 1

B. Were there times during the experiment at which you felt your motivation and interest were lagging? What were those times?

Yes - 3 No - 4	After 40 or 50 slides I felt my interest lagging - 1

II. Weapon Information

A. Were you familiar beforehand with the friendly and enemy weapons discussed in the experiment? With which ones were you least familiar?

Familiar with all weapons - 4
Familiar with 12.5 and 37 - 1
Slightly familiar with 14.5 - 1
Heard of all weapons but no personal experience with any - 1

Least familiar with Redeye - 4
Least familiar with 14.5 - 1
Least familiar with 23 - 1

B. Would additional information concerning the weapons be beneficial? What kind of information would be most helpful?

Yes - 3 No - 4	Pictures of weapons and their mountings - 2 Weapon effectiveness data in the form of probability of kill as a function of target range and aspect - 2 Maximum range of weapon - 1

C. Was enough time allowed for studying the weapon hand outs?

Yes - 7 The instructor should indicate the critical data that
No - 0 will be of use during the experiment - 1

D. If you were already familiar with the weapons, were the modified performance specifications confusing to you?

Yes - 0
No - 7

Did you use the information as presented?

Yes - 5
No - 2 I used maximum range instead of maximum effective range - 1
I allowed for pure luck in 5 second exposure situations (stated reaction time was 8 seconds) - 1

E. Was the choice of weapons reasonable and representative of a mid-intensity environment?

Yes - 6 Some other types of weapons will probably be on the battlefield also - 1
The VC and NVA have done well with small arms and even RPG's - 1
No - 1

III. Terrain Information

A. Was the terrain and its forested areas represented with sufficient clarity?

Yes - 7
No - 0

Was the perspective drawing of the area of any benefit?

Yes - 5
No - 2 I had trouble relating the drawing to the map - 1
I did not look at the drawing - 1

B. Was the line of sight information beneficial or did it introduce artificiality? Would it be of benefit to have this information in combat?

Yes - 7	The information can be obtained by a good map study - 1
No - 0	The information is not available in combat - 1
	I do not know if it would work in combat - 1

IV. Threat Evaluation

A. Did you have difficulty in visualizing the situations presented to you in the 109 exposure slides?

Yes - 2	I had trouble at first - 1
No - 5	

Did you have particular difficulty in assigning a number to the threat you felt in the situations that were presented?

Yes - 2	The threat interval (0-1000) is too large. A scale of (1-10) or (1-100) would be more realistic - 1
No - 5	

Were some situations more difficult to evaluate than others?

Yes - 5	I had trouble with the short exposure time situations - 1
No - 2	

B. On each slide, the type of enemy weapon, the exposure time and the range to the enemy weapon (maximum and minimum) were given. In addition, the midpoint range was called out verbally. Were all these clues of benefit?

Yes - 7
No - 0

What other factors enter into your perception of the threat posed by a solitary enemy weapon?

Probability of kill as functions of range and attitude - 1
Luck - 1
Terrain, density of foliage - 1
Aircraft type and proficiency of crew - 1
There are so many variables it's a guessing game - 1

How long I am in his field of fire after his reaction time - 1
None - 1
(Each subject had a different answer)

C. Would you say that the threat you feel from the 14.5 mm and the 23 mm weapons is almost constant out to their respective maximum ranges, given a constant exposure time and bearing to the weapon?

14.5 mm	23 mm
Yes - 3	Yes - 7
No - 4	No - 0

Would you say that these weapons are more threatening in your rear quadrant at a given range, or does bearing have any effect?

More threatening from rear - 3
More threatening from side - 3
Makes little difference - 1

VI. Route Selection

A. Have you any comments concerning the situations for which you were to select a route? Were they artificial?

Yes - 6
- Some cases were - 1
- Only in the fact that the exact location and type of weapon was given - 2
- In combat, line of sight information is not available - 1
- I would not attack a weapon that had a greater effective range than I; there is a thin line between mission accomplishment and suicide - 1

No - 1

B. Were you permitted sufficient latitude in the tactics to be used during the attack?

Yes - 6 Not enough is known about tactics in this type of environment - 1
No - 0

C. In general, can you describe the differences between two attack situations that would lead you to select hovering fire in one and running fire in the other?

-Running fire is a method of attack used during periods of high density conditions, or when there is a lack of suitable terrain to allow engagement at maximum effective range of the weapon system.

-If I were attacking a target inside that weapon's range, I would prefer to be moving when I am attacking. If I am outside that weapon's effective range or I feel he has a relatively slight chance of hitting me, then I would fire from the hovering position.

-It would depend on how close I could get to the target without being seen.

-I would use hovering fire only if I could locate a firing position that has high vegetation or terrain behind it so I would not be silhouetted against the sky.

-I cannot set up conditions for hovering versus running fire because I've never (in combat) seen a need for it. (Times change)

-My answers were explained on the Master Information Form.

-Hovering fire is better if cover is available and your max effective range is greater than that of the enemy. When you must expose yourself inside the enemy's range, running fire is better.

D. In selecting a launch range, did you trade off kill probability against exposure time?

Yes - 5
No - 2

What criterion did you use in arriving at a launch range?

-Terrain was the major criterion; I tried to engage at maximum effective range.

-I would rather take a few more chances of being hit than miss the target and have to engage again.

-I tried to maximize kill probability while exposing myself for less time than the reaction time of the enemy.

-I considered the visibility, effective range and time to react of the enemy.

-I tried to minimize my exposure inside the enemy's effective range.

E. What would best describe the way you selected routes? Did you minimize travel time or exposure?

Exposure - 7	Minimum exposure is critical - 2
Travel time - 0	Travel time is immaterial - 2

Did you maximize the element of surprise?

Yes (attempted to) - 7	Surprise is nice but not necessary - 1
No - 0	Minimum exposure produces surprise - 1

Did you try to remain out of the effective range of the enemy weapons?

Yes (attempted to) - 6	
No - 0	Minimum exposure is critical even beyond maximum effective range of 23 mm - 1
	23 mm had enough range to prevent this tactic - 2

VI. Other

The information you get from us may not be very valid. Not enough is known about mid-intensity employment of helicopters. More development, other than yours, is needed - 1

Table F.1

Alternative Numbering Scheme

		A. T.		1		3	
Subject	Route	RF	HF	RF	HF	RF	HF
6	1	1	4	2	5	3	6
	3	1	4	2	5	3	5
7	1	1	4	2	5	3	4
	3	1	4	2	5	3	6
8	1	1	3	2	4	1	5
	3	1	4	2	5	3	4
11	1	1	4	2	5	3	6
	3	1	4	2	5	3	6
12	1	1	3	2	4	1	3
	3	1	4	2	5	3	4
13	1	1	4	2	5	3	6
	3	1	4	2	5	3	6

Table F. 2

Summary of Similarity in Routes Produced by the Three Threat Perception Models

		Between Acid Test Model and Model Three				Between Model One and Model Three			
Subject	Route	RF	HF	Similarity (%)	Totals (%)	RF	HF	Similarity (%)	Totals (%)
6	1	0	0	0		0	0	0	
	3	0	0	0	0	0	1	50	25
7	1	0	1	50		0	0	0	
	3	0	0	0	25	0	0	0	0
8	1	1	0	50		0	0	0	
	3	0	1	50	50	0	0	0	0
11	1	0	0	0		0	0	0	
	3	0	0	0	0	0	0	0	0
12	1	1	1	100		0	0	0	
	3	0	1	50	75	0	0	0	0
13	1	0	0	0		0	0	0	
	3	0	0	0	0	0	0	0	0
Totals (%)		17	33		25	0	8		4

1 - route produced by one of the two models is the same as that produced by the other

0 - different routes are produced

Table F.3

Summary of Similarity in Route Alternatives
Presented to Comparable Subjects

Subject Pair	Route	First Subject Alternatives						Second Subject Alternatives						% Similarity
		1	2	3	4	5	6	1	2	3	4	5	6	
(7, 11)	1	1	1	0	1	1	1	0	1	1	0	1	1	75
	3	0	1	0	0	1	0	0	1	0	0	1	0	33
(8, 12)	1	1	1	0	1	1	1	1	1	1	1	1	1	92
	3	0	1	1	1	1	1	0	1	1	1	1	1	83
Total for (7, 11) (%)														54
Total for (8, 12) (%)														88
Overall														71

- 1 - at least one route alternative of paired subject is the same as the alternative in question

0 - no comparable route alternative exists for paired subject

Table F.4

Alternative Route Ratings

		A.T.		1		3	
Subject	Route	RF	HF	RF	HF	RF	HF
6	1	0.75	0.50	0.97	0.75	0.50	0.70
	3	0.40	1.00	0.85	0.93	0.67	0.93
7	1	0.80	0.95	1.00	0.95	0.96	0.95
	3	1.00	1.05	1.00	1.00	0.90	0.75
8	1	0.75	0.85	1.00	1.00	0.75	1.05
	3	1.05	0.65	1.00	1.00	0.80	0.65
11	1	0.97	0.80	0.99	0.60	0.74	0.10
	3	0.85	0.75	1.03	1.05	0.80	0.85
12	1	0.76	0.97	0.70	0.70	0.76	0.97
	3	0.60	0.40	0.50	0.40	0.60	0.40
13	1	0.30	0.30	1.00	1.00	0.30	0.30
	3	0.05	0.05	0.85	1.00	0.05	0.01

Table F.5

Route Ratings as Functions of Exposure Time

Subject	Route	Entry Code*	Subject Route	Alternatives					
				Running Fire			Hover Fire		
				AT	1	3	AT	1	3
6	1	R	100	75	97	50	50	75	70
		A	9	227	13	210	222	12	178
		1	13	0	0	0	0	0	0
		2	0	0	2	0	0	0	0
		3	9	227	13	210	222	12	178
		T	22	227	15	210	222	12	178
	3	R	100	40	85	67	100	93	93
		A	20	10	12	14	23	11	11
		1	86	190	12	166	0	0	0
		2	0	140	0	109	0	0	0
		3	20	254	12	160	23	11	11
		T	106	584	24	435	23	11	11
7	1	R	100	80	100	96	95	95	95
		A	98	15	10	18	92	13	92
		1	0	0	0	0	0	0	0
		2	119	56	40	57	127	0	127
		3	89	39	10	64	92	13	92
		T	217	95	50	121	219	13	219
	3	R	100	100	100	90	105	100	75
		A	82	10	10	11	22	9	12
		1	75	211	40	117	211	40	117
		2	0	0	0	0	0	0	0
		3	82	10	10	177	22	9	178
		T	157	221	50	294	233	49	295
8	1	R	100	75	100	75	85	100	105
		A	112	18	10	18	36	11	47
		1	0	0	0	0	0	0	0
		2	24	113	30	113	125	30	122
		3	112	49	10	49	36	11	47
		T	136	152	40	152	161	41	169
	3	R	100	105	100	80	65	100	65
		A	19	18	15	18	21	21	21
		1	35	44	50	76	119	30	119
		2	0	7	0	7	0	0	0
		3	19	142	15	124	85	21	85
		T	54	193	65	207	204	51	204

Table F. 5 (Continued)

11	1	R	100	97	99	74	80	60	10
		A	12	10	10	15	8	13	92
		1	0	0	0	0	0	0	0
		2	27	171	32	45	171	0	102
		3	25	10	10	35	8	13	92
		T	52	181	42	80	188	13	194
	3	R	100	85	103	80	75	105	85
		A	11	7	10	14	13	9	12
		1	27	177	32	170	171	32	170
		2	0	0	0	0	0	0	0
		3	11	7	10	14	13	9	12
		T	38	184	42	184	184	41	182
12	1	R	100	76	70	76	97	70	97
		A	97	18	10	18	47	11	47
		1	0	0	0	0	0	0	0
		2	33	102	27	102	110	27	110
		3	97	45	10	45	47	11	47
		T	130	147	37	147	157	38	157
	3	R	100	60	50	60	40	40	40
		A	11	18	15	18	21	21	21
		1	130	102	46	69	108	27	108
		2	0	0	0	0	0	0	0
		3	103	103	15	114	79	21	79
		T	233	205	61	183	187	48	187
13	1	R	100	30	100	30	30	100	30
		A	42	10	7	7	9	9	9
		1	0	39	2	38	39	0	36
		2	0	0	0	0	0	0	0
		3	64	101	33	99	100	35	100
		T	64	140	35	137	139	35	136
	3	R	100	5	85	5	5	100	1
		A	21	13	15	18	21	21	10
		1	0	19	16	18	0	0	10
		2	0	50	0	0	41	0	15
		3	42	173	41	156	112	47	196
		T	42	242	57	174	153	47	221

*R - rating
A - time exposed during attack (seconds)
1 - time exposed to target weapon only (seconds)
2 - time exposed to supporting weapon only (seconds)
3 - time exposed to both weapons simultaneously (seconds)
T - time exposed to one or more weapons (seconds)

Table F.6

Total Route Threat Estimates
(Method of threat evaluation corresponds to method used during route selection.)

		Perception Model					
		A. T.		1		3	
Subject	Route	RF	HF	RF	HF	RF	HF
6	1	78.62	65.57	2.81	2.51	.0307	.0275
	3	355.69	517.60	3.56	2.24	1.4751	1.7492
7	1	109.77	341.61	6.09	2.69	.0370	.0482
	3	278.33	172.67	6.05	5.89	1.2343	1.2275
8	1	89.08	119.85	5.05	5.32	.0269	.0370
	3	408.11	157.65	8.17	7.21	1.7799	2.1007
11	1	286.82	327.81	5.30	2.68	3.0721	.0406
	3	364.94	404.99	5.26	5.09	2.1627	1.9130
12	1	22.43	31.02	4.75	5.02	.0244	.0338
	3	884.89	35.92	7.67	6.91	1.7769	2.0966
13	1	99.54	97.19	6.90	6.97	1.5482	1.5838
	3	474.79	472.23	9.86	9.35	3.2169	4.0177

Exhibit F. 2

Trial Two Experiment Mailer

This exhibit represents a sample of the mailer distributed to each subject during the Trial Two Experiment. It is actually a copy of the mailer received by subject 7 and contains the responses he prepared.

THE OHIO STATE UNIVERSITY

28 February 1972

MEMO:

(Names omitted for anonymity)

FROM: Don C. Hutcherson

During our last session together several subjects had very constructive comments regarding undesirable characteristics of the attack routes selected through computer analysis. The fact that the route alternatives were not as good as desired was subsequently revealed in the rating data that were collected.

Based on comments received, the computer model has been modified and the analyses have been repeated. However, the number of subjects has been reduced to six, only alternatives for subject routes one and three have been prepared, and the number of alternatives for each route has been reduced.

I am asking that you provide me with comparison data for the routes prepared by the new computer model. Your familiarity with the problem coupled with the reduced amount of analysis required should permit you to complete the work in thirty (30) minutes at the most.

Please take a few minutes and provide me with the desired information at your earliest opportunity. In order to meet my deadlines here, I must have your response in my possession by 8 March 1972. Your cooperation is appreciated by me personally and by Systems Analysis Group, Combat Developments Command.

Instructions

1. Read the attached description of enclosures.

2. Carefully examine the enclosures for understanding.

3. Perform the comparisons in a fashion identical to that used during our last session:

   a) If an alternative is definitely the same in value as your route, rate it 100 in column five and check the first column of the answer sheet.

   b) If you are almost indifferent, rate the "non-preferred" route between 95 and 100 in column five and enter "my route" or "computer route" in column two to indicate which one is preferred.

   c) If you mildly prefer one route to another, rate the "non-preferred" route between 70 and 95 in column five and enter "my route" or "computer route" in column three to indicate which one is preferred.

   d) If you strongly prefer one route to another, rate the "non-preferred" route between 0 and 70 in column five and enter "my route" or "computer route" in column four to indicate which one is preferred.

4. As before, the alternatives are sequentially numbered and there may be a different number of alternatives to route one than there are to route three. A maximum of six alternatives can exist.

5. The computer plot of your route is included for information only. Naturally, it is not to be rated as it represents your route. It was taken from the original acetate tracing.

6. Mail the entire package in the postage free envelope provided. I should receive your response by 8 March 1972.

Description of Enclosures

You will find the following material enclosed for each of your routes (routes 1 and 3).

1. The contour map upon which you transferred your route during our last session.

2. A plot of your route prepared by the computer.

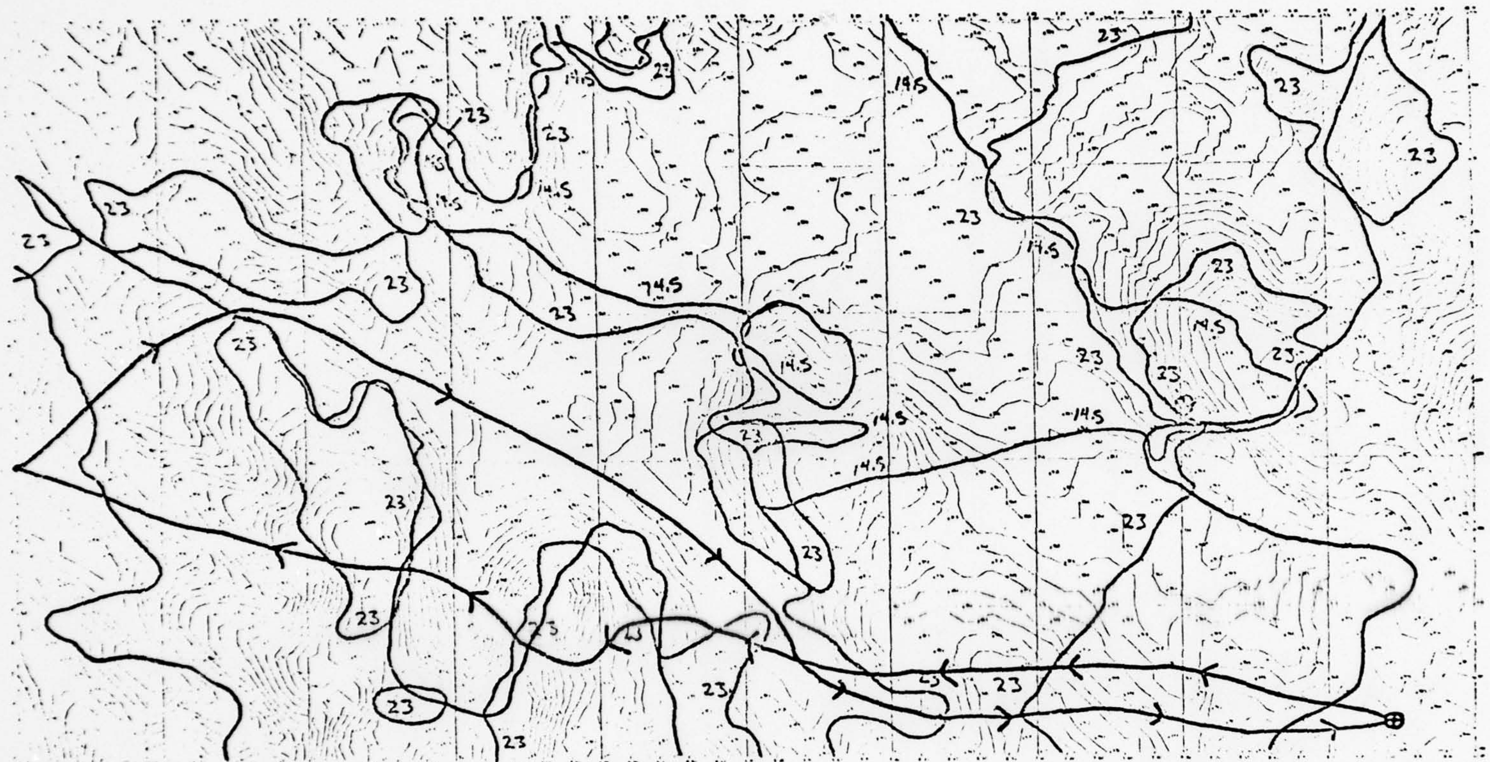
3. A statistic sheet giving basic information about your route as determined by the computer.

4. A plot of alternatives to your route as prepared by the computer.

5. Statistic sheets giving basic information about each alternative as determined by the computer.

6. An answer sheet to record your comparison information. (Any additional comments are appreciated and can be entered on the answer sheet.)

Items 2, 3, and 5 are new and are enclosed to assist you in your evaluation of alternatives. They give detailed information that was not available during the last session. Such information may be especially valuable in judging your own route in relation to the alternatives.

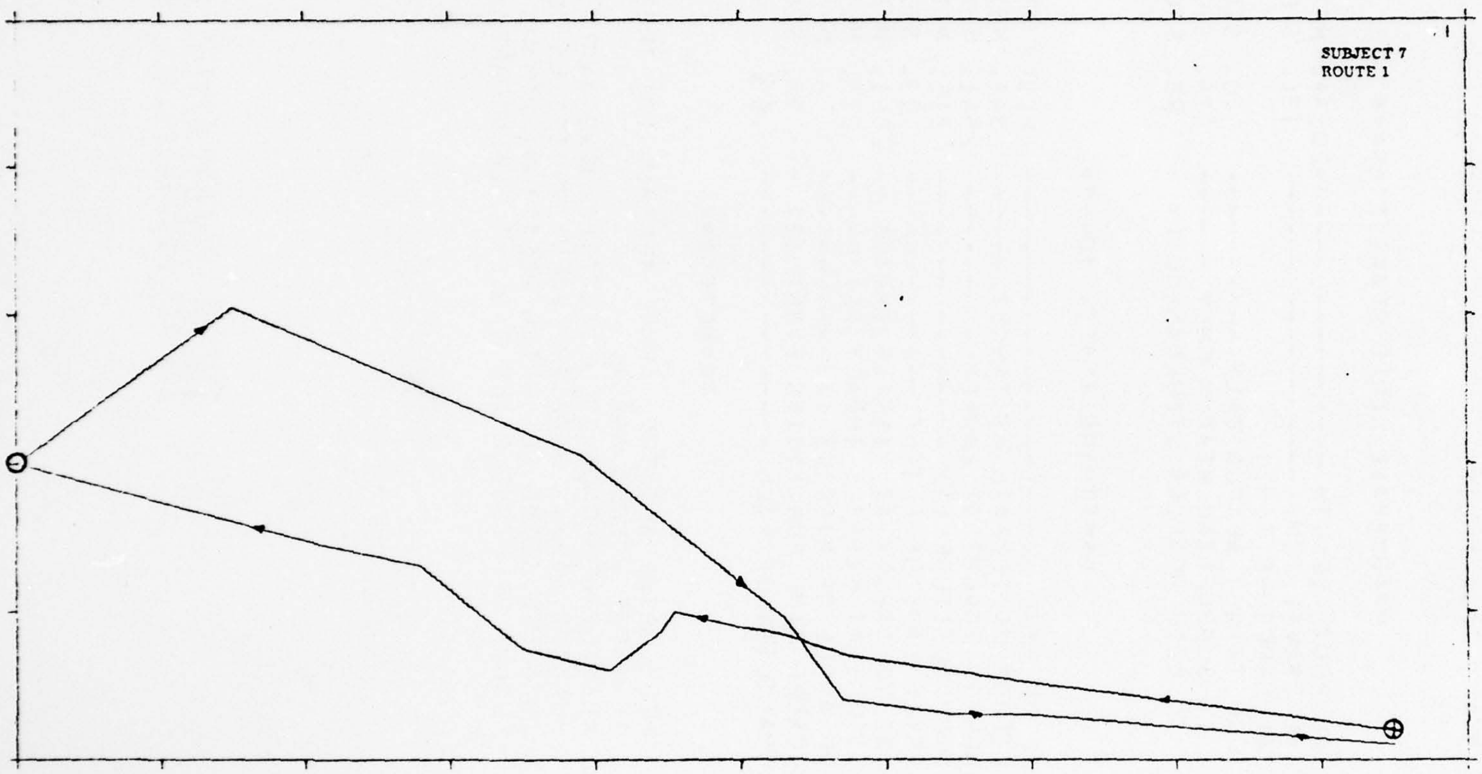


X AXIS (KILOMETERS)

SUBJECT 7

Rt. 1

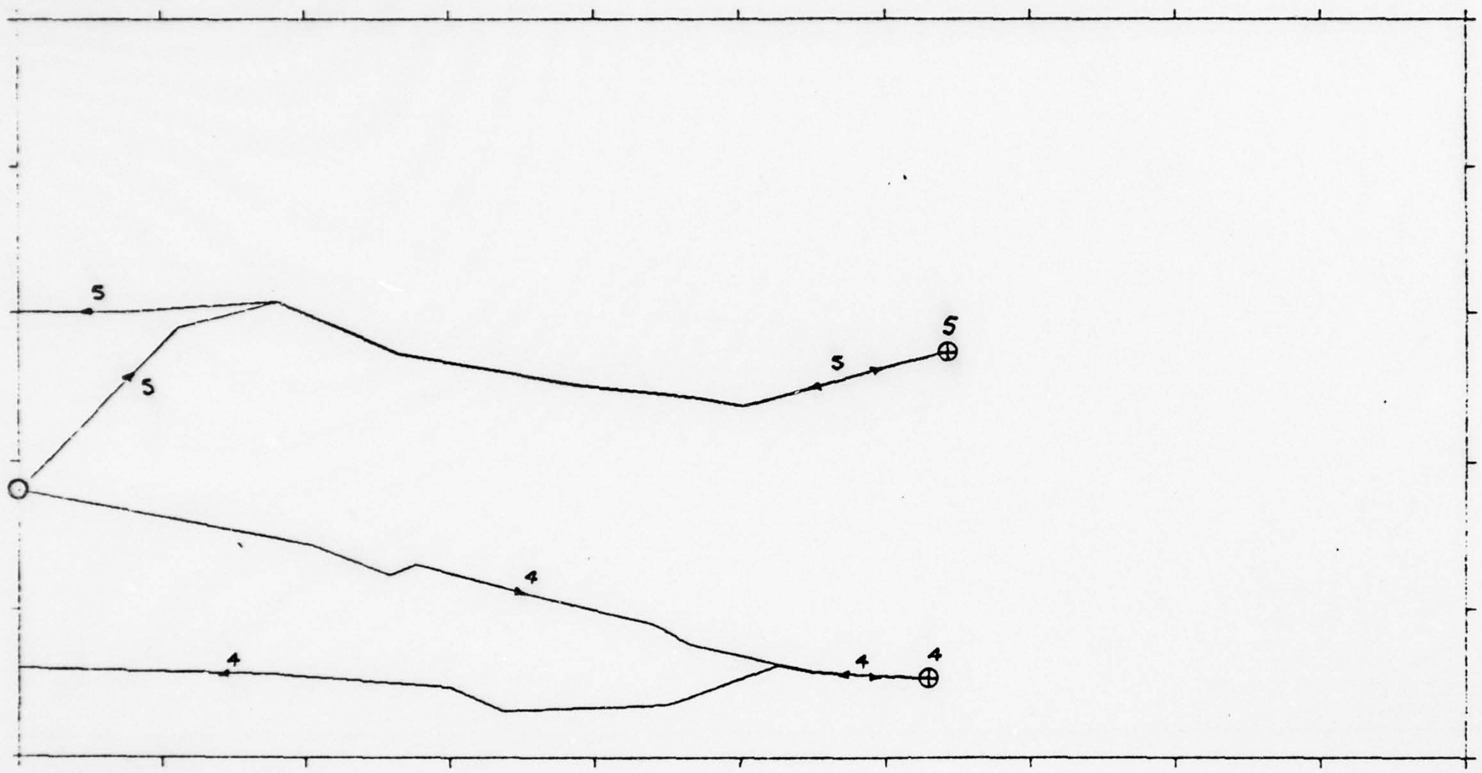
Original size of map: 7.5 x 14.5 inches



Original size of map: 7.5 x 14.5 inches

S 7 R 1 OWN CHOICE

```
              ***OVERALL ROUTE STATISTICS***

TOTAL ROUTE LENGTH -----------------20834. METERS
TOTAL TRAVEL TIME ------------------  730. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ----------    0. SECONDS
    TO SUPPORTING WEAPON ONLY ------  119. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY -   98. SECONDS

              ***FIRING STATISTICS***

TYPE OF FIRE ----------------------  HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  349. METERS
RANGE TO TARGET AT LAUNCH ---------- 2541. METERS
LAUNCH ALTITUDE (1) ----------------  215. METERS
MISSILE TIME OF FLIGHT -------------   13. SECONDS
RANGE TO TARGET AT MISSILE IMPACT -- 2541. METERS
ALTITUDE AT MISSILE IMPACT (1) -----  215. METERS
DIVE ANGLE OF MISSILE (2) ----------    6. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   98. SECONDS
PROBABILITY OF KILL ---------------- .65

                    ***NOTES***

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS
    IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR
    RUNNING FIRE.  NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY,
    FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.
```



SUBJECT 7 ROUTE 1 ALTERNATIVES (HOVER FIRE)

Original size of map: 7.5 x 14.5 inches

AD-A045 094 OHIO STATE UNIV COLUMBUS SYSTEMS RESEARCH GROUP F/G 1/2
THE HELICOPTER ROUTE SELECTION MODEL (DYNFLITE).(U)
AUG 76 G M CLARK, D C HUTCHERSON, D C BITTERS DAAG25-70-C-0311
UNCLASSIFIED RF-2978-FR-76-4(0) NL

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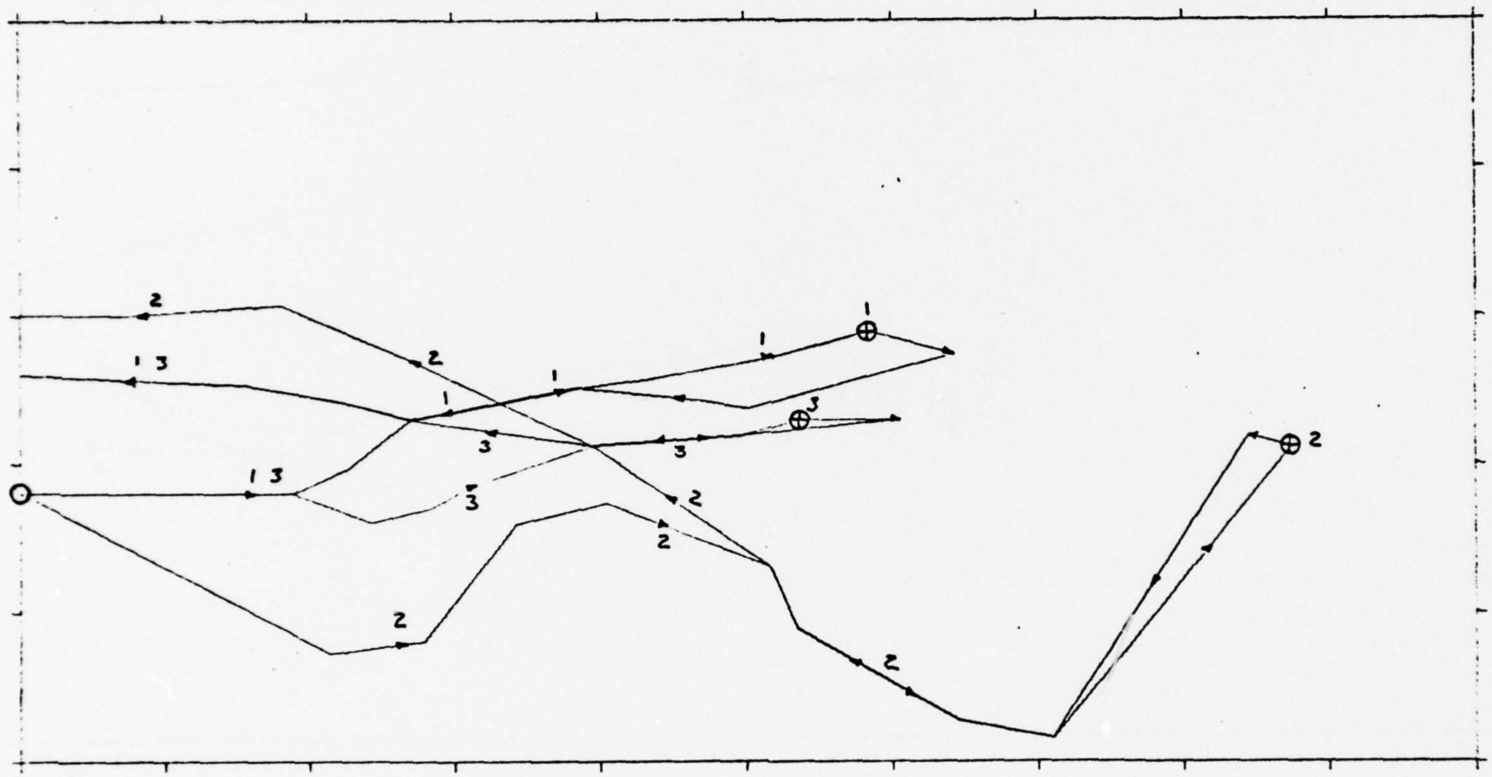
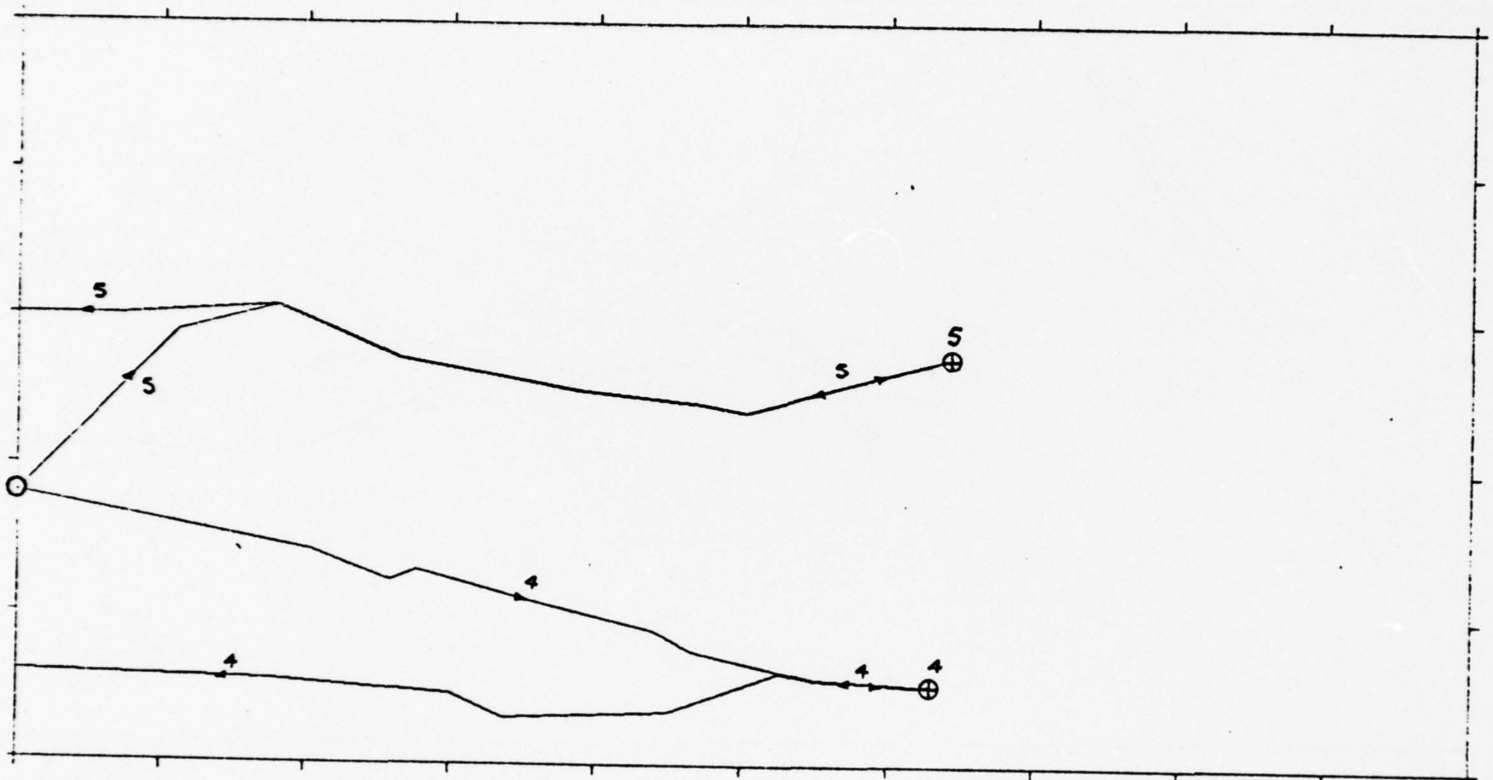


SUBJECT 7 ROUTE 1 ALTERNATIVES (RUNNING FIRE)

Original size of map: 7.5 x 14.5 inches



SUBJECT 7 ROUTE 1 ALTERNATIVES (HOVER FIRE)

Original size of map: 7.5 x 14.5 inches

SUBJECT 7 ROUTE 1 RUNNING FIRE [redacted]

ALT 1

OVERALL ROUTE STATISTICS

TOTAL ROUTE LENGTH ------------------	13204.	METERS
TOTAL TRAVEL TIME ------------------	397.	SECONDS
TOTAL EXPOSURE TIME:		
TO TARGET WEAPON ONLY ----------	0.	SECONDS
TO SUPPORTING WEAPON ONLY ------	56.	SECONDS
TO BOTH WEAPONS SIMULTANEOUSLY -	39.	SECONDS

FIRING STATISTICS

TYPE OF FIRE -----------------------	RUNNING FIRE	
ALTITUDE OF TERRAIN AT TARGET ------	349.	METERS
RANGE TO TARGET AT LAUNCH ----------	2100.	METERS
LAUNCH ALTITUDE (1) ----------------	19.	METERS
MISSILE TIME OF FLIGHT -------------	10.	SECONDS
RANGE TO TARGET AT MISSILE IMPACT --	1689.	METERS
ALTITUDE AT MISSILE IMPACT (1) -----	18.	METERS
DIVE ANGLE OF MISSILE (2) ----------	0.	DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -	15.	SECONDS
PROBABILITY OF KILL ---------------	.74	

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

SUBJECT 7 ROUTE 1 RUNNING FIRE [redacted]

ALT 2

OVERALL ROUTE STATISTICS

```
TOTAL ROUTE LENGTH ------------------21583. METERS
TOTAL TRAVEL TIME ------------------  655. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ----------    0. SECONDS
    TO SUPPORTING WEAPON ONLY ------   40. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY -   10. SECONDS
```

FIRING STATISTICS

```
TYPE OF FIRE ----------------------  RUNNING FIRE
ALTITUDE OF TERRAIN AT TARGET ------  349. METERS
RANGE TO TARGET AT LAUNCH ----------  435. METERS
LAUNCH ALTITUDE (1) ----------------   27. METERS
MISSILE TIME OF FLIGHT -------------    2. SECONDS
RANGE TO TARGET AT MISSILE IMPACT --  399. METERS
ALTITUDE AT MISSILE IMPACT (1) -----   10. METERS
DIVE ANGLE OF MISSILE (2) ----------    6. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   10. SECONDS
PROBABILITY OF KILL ----------------  .92
```

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

SUBJECT 7 ROUTE 1 RUNNING FIRE [redacted]

ALT 3

OVERALL ROUTE STATISTICS

TOTAL ROUTE LENGTH ------------------12310. METERS
TOTAL TRAVEL TIME ------------------ 370. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ---------- 0. SECONDS
    TO SUPPORTING WEAPON ONLY ------ 57. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY - 64. SECONDS

FIRING STATISTICS

TYPE OF FIRE ---------------------- RUNNING FIRE
ALTITUDE OF TERRAIN AT TARGET ------ 349. METERS
RANGE TO TARGET AT LAUNCH ---------- 2500. METERS
LAUNCH ALTITUDE (1) ---------------- 18. METERS
MISSILE TIME OF FLIGHT ------------- 13. SECONDS
RANGE TO TARGET AT MISSILE IMPACT -- 2012. METERS
ALTITUDE AT MISSILE IMPACT (1) ----- 18. METERS
DIVE ANGLE OF MISSILE (2) ---------- 1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) - 18. SECONDS
PROBABILITY OF KILL ---------------- .65

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

SUBJECT 7 ROUTE 1 HOVER FIRE [redacted]

ALT 4

```
              ***OVERALL ROUTE STATISTICS***

TOTAL ROUTE LENGTH ------------------12882. METERS
TOTAL TRAVEL TIME -------------------  482. SECONDS
TOTAL EXPOSURE TIME:
     TO TARGET WEAPON ONLY ----------    0. SECONDS
     TO SUPPORTING WEAPON ONLY ------  127. SECONDS
     TO BOTH WEAPONS SIMULTANEOUSLY -   92. SECONDS

                ***FIRING STATISTICS***

TYPE OF FIRE -----------------------  HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  349. METERS
RANGE TO TARGET AT LAUNCH ---------- 2500. METERS
LAUNCH ALTITUDE (1) ----------------  207. METERS
MISSILE TIME OF FLIGHT -------------   13. SECONDS
RANGE TO TARGET AT MISSILE IMPACT -- 2500. METERS
ALTITUDE AT MISSILE IMPACT (1) -----  207. METERS
DIVE ANGLE OF MISSILE (2) ----------    6. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   92. SECONDS
PROBABILITY OF KILL ----------------  .65

                     ***NOTES***

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS
    IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR
    RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY,
    FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.
```

SUBJECT 7 ROUTE 1 HOVER FIRE [redacted]

ALT 5

OVERALL ROUTE STATISTICS

```
TOTAL ROUTE LENGTH -----------------13616. METERS
TOTAL TRAVEL TIME ------------------  426. SECONDS
TOTAL EXPOSURE TIME:
     TO TARGET WEAPON ONLY ----------    0. SECONDS
     TO SUPPORTING WEAPON ONLY ------    0. SECONDS
     TO BOTH WEAPONS SIMULTANEOUSLY -   13. SECONDS
```

FIRING STATISTICS

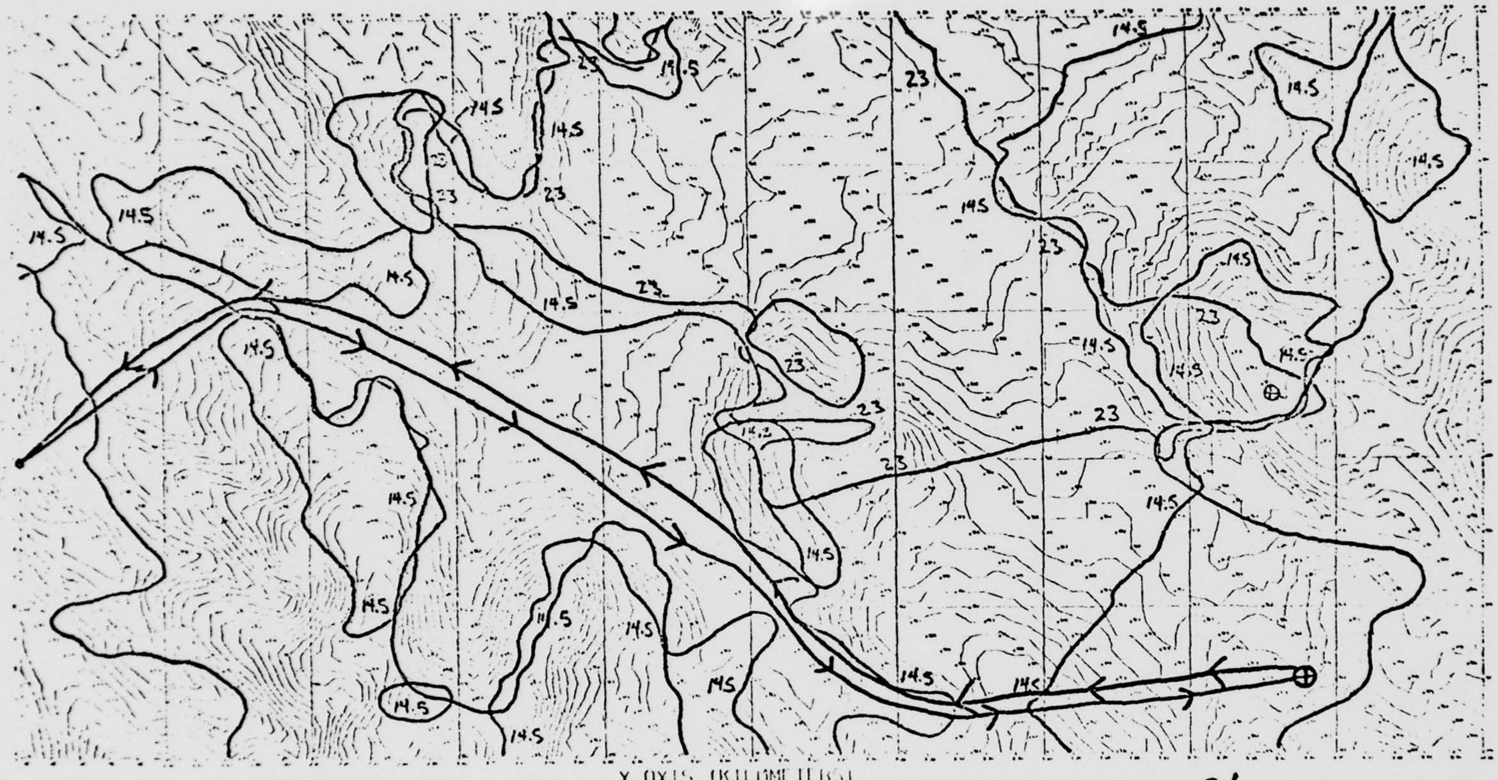
```
TYPE OF FIRE -----------------------  HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  349. METERS
RANGE TO TARGET AT LAUNCH ---------- 1700. METERS
LAUNCH ALTITUDE (1) ----------------   18. METERS
MISSILE TIME OF FLIGHT -------------    8. SECONDS
RANGE TO TARGET AT MISSILE IMPACT -- 1700. METERS
ALTITUDE AT MISSILE IMPACT (1) -----   18. METERS
DIVE ANGLE OF MISSILE (2) ----------    0. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   13. SECONDS
PROBABILITY OF KILL ----------------  .78
```

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

Subject 7 Alternatives for Route 1

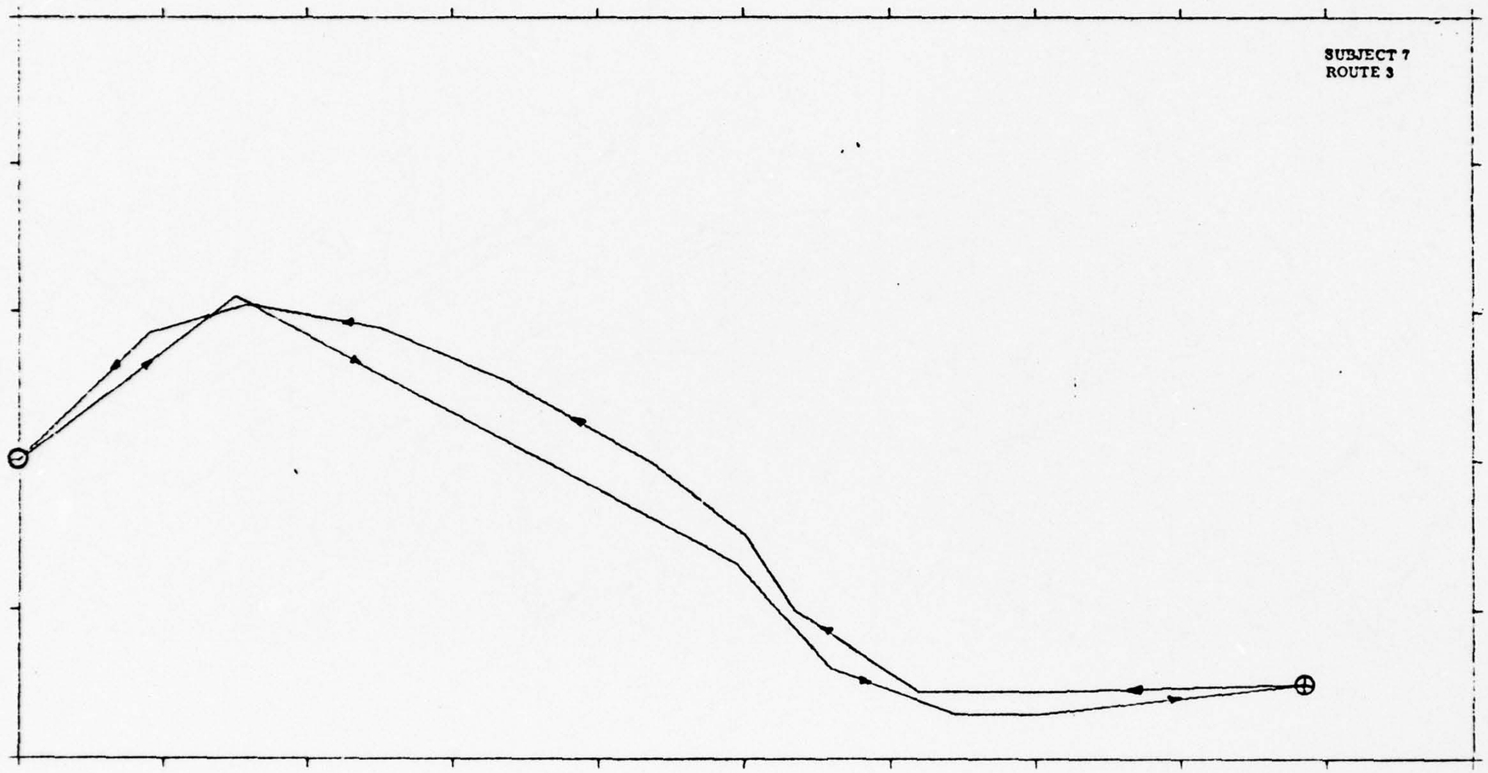
Alternate Route	Definitely Indifferent (100)	Almost Indifferent (100)	Mildly Prefer Route (95)	Strongly Prefer Route (75)	Rating of Inferior Route (0)
1			My Route		80
2	✓				100
3		My Route			96
4		My Route			95
5		My Route			95



SUBJECT 7

Rt. 3

Original size of map: 7.5 x 14.5 inches



Original size of map: 7.5 x 14.5 inches

S 7 R 3 OWN CHOICE

OVERALL ROUTE STATISTICS

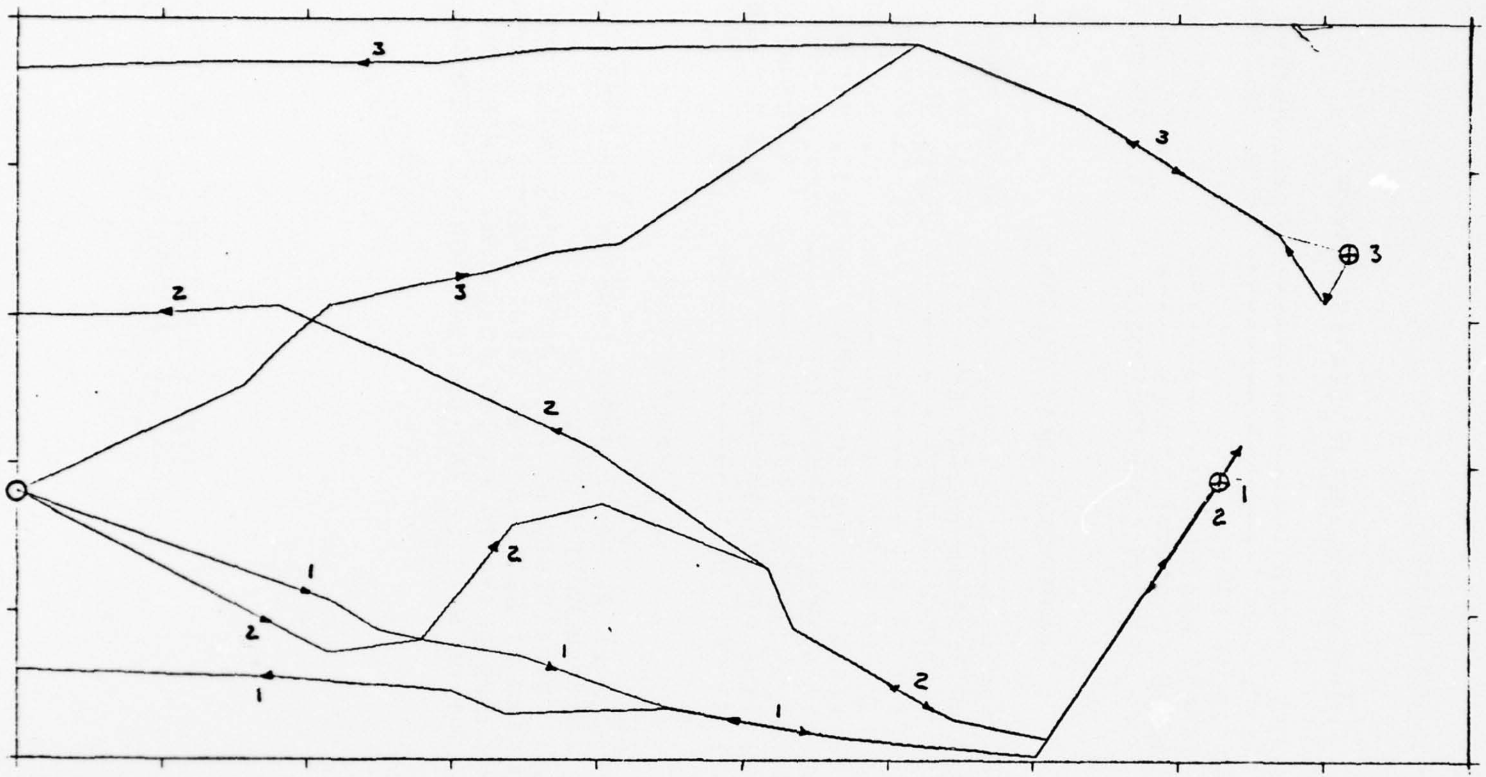
```
TOTAL ROUTE LENGTH ------------------20051. METERS
TOTAL TRAVEL TIME ------------------  690. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ----------   75. SECONDS
    TO SUPPORTING WEAPON ONLY ------    0. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY -   82. SECONDS
```

FIRING STATISTICS

```
TYPE OF FIRE -----------------------  HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  386. METERS
RANGE TO TARGET AT LAUNCH ---------- 2011. METERS
LAUNCH ALTITUDE (1) ----------------  189. METERS
MISSILE TIME OF FLIGHT -------------   10. SECONDS
RANGE TO TARGET AT MISSILE IMPACT -- 2011. METERS
ALTITUDE AT MISSILE IMPACT (1) -----  189. METERS
DIVE ANGLE OF MISSILE (2) ----------    5. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   82. SECONDS
PROBABILITY OF KILL ----------------  .75
```

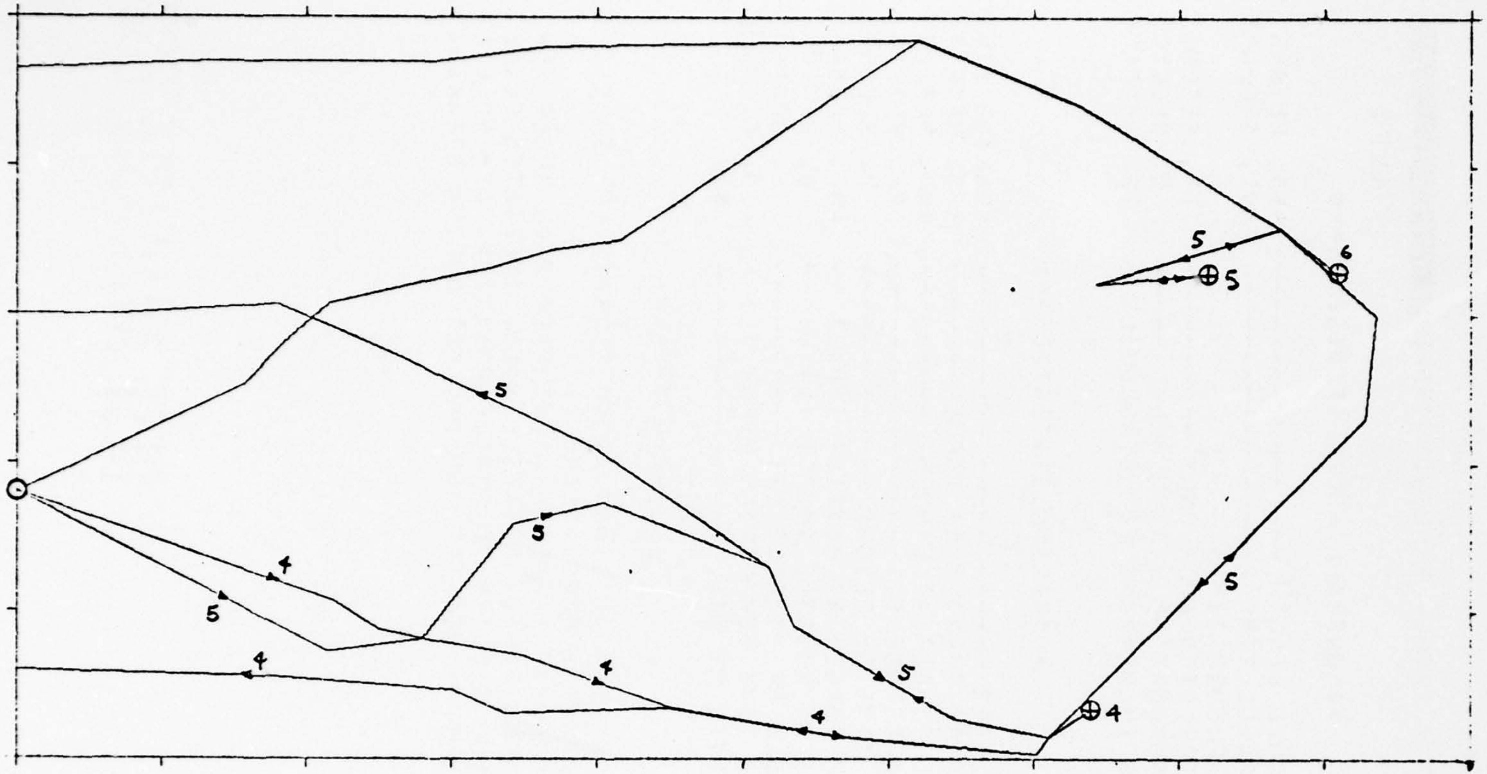
NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.



SUBJECT 7 ROUTE 3 ALTERNATIVES (RUNNING FIRE)

Original size of map: 7.5 x 14.5 inches



SUBJECT 7 ROUTE 3 ALTERNATIVES (HOVER FIRE)

Original size of map: 7.5 x 14.5 inches

SUBJECT 7 ROUTE 3 RUNNING FIRE [redacted]

ALT 1

OVERALL ROUTE STATISTICS

TOTAL ROUTE LENGTH ------------------	19465. METERS
TOTAL TRAVEL TIME ------------------	591. SECONDS
TOTAL EXPOSURE TIME:	
TO TARGET WEAPON ONLY ----------	211. SECONDS
TO SUPPORTING WEAPON ONLY ------	0. SECONDS
TO BOTH WEAPONS SIMULTANEOUSLY -	10. SECONDS

FIRING STATISTICS

TYPE OF FIRE -----------------------	RUNNING FIRE
ALTITUDE OF TERRAIN AT TARGET ------	386. METERS
RANGE TO TARGET AT LAUNCH ----------	500. METERS
LAUNCH ALTITUDE (1) ----------------	26. METERS
MISSILE TIME OF FLIGHT -------------	2. SECONDS
RANGE TO TARGET AT MISSILE IMPACT --	402. METERS
ALTITUDE AT MISSILE IMPACT (1) -----	10. METERS
DIVE ANGLE OF MISSILE (2) ----------	1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -	10. SECONDS
PROBABILITY OF KILL ----------------	.92

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

BEST AVAILABLE COPY

SUBJECT 7 ROUTE 3 RUNNING FIRE [redacted]

ALT 2

OVERALL ROUTE STATISTICS

TOTAL ROUTE LENGTH ------------------	21078. METERS
TOTAL TRAVEL TIME ------------------	639. SECONDS
TOTAL EXPOSURE TIME:	
TO TARGET WEAPON ONLY ----------	40. SECONDS
TO SUPPORTING WEAPON ONLY ------	0. SECONDS
TO BOTH WEAPONS SIMULTANEOUSLY -	10. SECONDS

FIRING STATISTICS

TYPE OF FIRE ----------------------	RUNNING FIRE
ALTITUDE OF TERRAIN AT TARGET ------	386. METERS
RANGE TO TARGET AT LAUNCH ----------	500. METERS
LAUNCH ALTITUDE (1) ----------------	26. METERS
MISSILE TIME OF FLIGHT -------------	2. SECONDS
RANGE TO TARGET AT MISSILE IMPACT --	402. METERS
ALTITUDE AT MISSILE IMPACT (1) -----	10. METERS
DIVE ANGLE OF MISSILE (2) ----------	1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -	10. SECONDS
PROBABILITY OF KILL ----------------	.92

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

SUBJECT 7 ROUTE 3 RUNNING FIRE [redacted]

ALT 3

OVERALL ROUTE STATISTICS

```
TOTAL ROUTE LENGTH ------------------20301. METERS
TOTAL TRAVEL TIME ------------------  615. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ----------  117. SECONDS
    TO SUPPORTING WEAPON ONLY ------    0. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY -  177. SECONDS
```

FIRING STATISTICS

```
TYPE OF FIRE -----------------------  RUNNING FIRE
ALTITUDE OF TERRAIN AT TARGET ------  386. METERS
RANGE TO TARGET AT LAUNCH ----------  895. METERS
LAUNCH ALTITUDE (1) ----------------   28. METERS
MISSILE TIME OF FLIGHT -------------    4. SECONDS
RANGE TO TARGET AT MISSILE IMPACT --  720. METERS
ALTITUDE AT MISSILE IMPACT (1) -----   21. METERS
DIVE ANGLE OF MISSILE (2) ----------   -1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   11. SECONDS
PROBABILITY OF KILL ----------------  .86
```

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

SUBJECT 7 ROUTE 3 HOVER FIRE [redacted]

ALT 4

OVERALL ROUTE STATISTICS

```
TOTAL ROUTE LENGTH ------------------15335. METERS
TOTAL TRAVEL TIME ------------------  486. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ----------  211. SECONDS
    TO SUPPORTING WEAPON ONLY ------    0. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY -   22. SECONDS
```

FIRING STATISTICS

```
TYPE OF FIRE -----------------------  HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  386. METERS
RANGE TO TARGET AT LAUNCH ---------- 2500. METERS
LAUNCH ALTITUDE (1) ----------------   23. METERS
MISSILE TIME OF FLIGHT -------------   13. SECONDS
RANGE TO TARGET AT MISSILE IMPACT -- 2500. METERS
ALTITUDE AT MISSILE IMPACT (1) -----   29. METERS
DIVE ANGLE OF MISSILE (2) ----------    1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   22. SECONDS
PROBABILITY OF KILL ----------------  .65
```

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

SUBJECT 7 ROUTE 3 HOVER FIRE [redacted]

ALT 5

```
***OVERALL ROUTE STATISTICS***

TOTAL ROUTE LENGTH -------------------29718. METERS
TOTAL TRAVEL TIME -------------------  909. SECONDS
TOTAL EXPOSURE TIME:
     TO TARGET WEAPON ONLY -----------   40. SECONDS
     TO SUPPORTING WEAPON ONLY -------    0. SECONDS
     TO BOTH WEAPONS SIMULTANEOUSLY -     9. SECONDS

***FIRING STATISTICS***

TYPE OF FIRE ------------------------ HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  386. METERS
RANGE TO TARGET AT LAUNCH ----------  900. METERS
LAUNCH ALTITUDE (1) ----------------   18. METERS
MISSILE TIME OF FLIGHT -------------    4. SECONDS
RANGE TO TARGET AT MISSILE IMPACT --  900. METERS
ALTITUDE AT MISSILE IMPACT (1) -----   18. METERS
DIVE ANGLE OF MISSILE (2) ----------   -1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -    9. SECONDS
PROBABILITY OF KILL ----------------  .86

***NOTES***

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS
    IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR
    RUNNING FIRE.  NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY,
    FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.
```

SUBJECT 7 ROUTE 3 HOVER FIRE [redacted]

ALT 6

OVERALL ROUTE STATISTICS

```
TOTAL ROUTE LENGTH ------------------19856. METERS
TOTAL TRAVEL TIME ------------------   613. SECONDS
TOTAL EXPOSURE TIME:
    TO TARGET WEAPON ONLY ----------   117. SECONDS
    TO SUPPORTING WEAPON ONLY ------     0. SECONDS
    TO BOTH WEAPONS SIMULTANEOUSLY -   178. SECONDS
```

FIRING STATISTICS

```
TYPE OF FIRE -----------------------  HOVER FIRE
ALTITUDE OF TERRAIN AT TARGET ------  386. METERS
RANGE TO TARGET AT LAUNCH ----------  900. METERS
LAUNCH ALTITUDE (1) ----------------   25. METERS
MISSILE TIME OF FLIGHT -------------    4. SECONDS
RANGE TO TARGET AT MISSILE IMPACT --  900. METERS
ALTITUDE AT MISSILE IMPACT (1) -----   25. METERS
DIVE ANGLE OF MISSILE (2) ----------   -1. DEGREES
EXPOSURE TIME FOR FIRING EVENT (3) -   12. SECONDS
PROBABILITY OF KILL ----------------  .96
```

NOTES

(1) HELICOPTER ALTITUDE ABOVE TERRAIN (OR TREE TOPS IF ABOVE WOODED AREA).
(2) ALSO CORRESPONDS TO HELICOPTER DIVE ANGLE FOR RUNNING FIRE. NEGATIVE VALUE INDICATES CLIMB.
(3) INCLUDES CLIMB TO FIRING POSITION, AIMING DELAY, FLIGHT OF MISSILE AND DESCENT DURING BREAKAWAY.

Subject 7 **Alternatives for Route** 3

Alternate Route	Definitely Indifferent (100)	Almost Indifferent (100)	Mildly Prefer Route (95)	Strongly Prefer Route (75)	Rating of Inferior Route (0)
1	✓				100
2	✓				100
3			My Route		90
4		Comp. Route			95
5	✓				100
6			My Route		75

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	12695.96	12695.96	$\sigma_e^2 + 12\ \sigma_1^2$	***
2-Route	1	6800.65	6800.65	$\sigma_e^2 + 12\ \sigma_2^2$	***
3-Perception Model	2	1014.08	507.04	$\sigma_e^2 + 6\ \sigma_3^2$	
4-Attack Mode	1	10.67	10.67	$\sigma_e^2 + 12\ \sigma_4^2$	
12	1	3313.52	3313.52	$\sigma_e^2 + 6\ \sigma_{12}^2$	**
13	2	183.29	91.64	$\sigma_e^2 + 4\ \sigma_{13}^2$	
14	1	937.54	937.54	$\sigma_e^2 + 6\ \sigma_{14}^2$	
23	2	75.60	37.80	$\sigma_e^2 + 4\ \sigma_{23}^2$	
24	1	60.18	60.18	$\sigma_e^2 + 6\ \sigma_{24}^2$	
34	2	123.08	61.54	$\sigma_e^2 + 4\ \sigma_{34}^2$	
Residual	9	3505.23	389.47	σ_e^2	
Total	23	28719.79			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.1 .--Analysis of Variance for Subject 6

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	66.67	66.67	$\sigma_e^2 + 12\,\sigma_1^2$	
2-Route	1	2.67	2.67	$\sigma_e^2 + 12\,\sigma_2^2$	
3-Perception Model	2	40.08	20.04	$\sigma_e^2 + 6\,\sigma_3^2$	
4-Attack Mode	1	4.17	4.17	$\sigma_e^2 + 12\,\sigma_4^2$	
12	1	4.17	4.17	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	308.58	154.29	$\sigma_e^2 + 4\,\sigma_{13}^2$	
14	1	2.67	2.67	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	322.58	161.29	$\sigma_e^2 + 4\,\sigma_{23}^2$	
24	1	0.00	0.00	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	273.58	136.79	$\sigma_e^2 + 4\,\sigma_{34}^2$	
Residual	9	936.66	104.07	σ_e^2	
Total	23	1961.83			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.2 .--Analysis of Variance for Subject 7

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	950.04	950.04	$\sigma_e^2 + 12\,\sigma_1^2$	
2- Route	1	2542.04	2542.04	$\sigma_e^2 + 12\,\sigma_2^2$	**
3- Perception Model	2	3729.25	1864.63	$\sigma_e^2 + 6\,\sigma_3^2$	**
4-Attack Mode	1	126.04	126.04	$\sigma_e^2 + 12\,\sigma_4^2$	
12	1	3675.38	3675.38	$\sigma_e^2 + 6\,\sigma_{12}^2$	**
13	2	370.09	185.04	$\sigma_e^2 + 4\,\sigma_{13}^2$	
14	1	26.04	26.04	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	1336.59	668.29	$\sigma_e^2 + 4\,\sigma_{23}^2$	
24	1	92.04	92.04	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	176.58	88.29	$\sigma_e^2 + 4\,\sigma_{34}^2$	
Residual	9	3293.55	365.95	σ_e^2	
Total	23	16317.62			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.3.--Analysis of Variance for Subject 8

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	24.00	24.00	$\sigma_e^2 + 12\ \sigma_1^2$	
2-Route	1	3700.17	3700.17	$\sigma_e^2 + 12\ \sigma_2^2$	*
3-Perception Model	2	1785.33	892.67	$\sigma_e^2 + 6\ \sigma_3^2$	
4-Attack Mode	1	1014.00	1014.00	$\sigma_e^2 + 12\ \sigma_4^2$	
12	1	216.00	216.00	$\sigma_e^2 + 6\ \sigma_{12}^2$	
13	2	444.00	222.00	$\sigma_e^2 + 4\ \sigma_{13}^2$	
14	1	337.50	337.50	$\sigma_e^2 + 6\ \sigma_{14}^2$	
23	2	1017.34	508.67	$\sigma_e^2 + 4\ \sigma_{23}^2$	
24	1	322.67	322.67	$\sigma_e^2 + 6\ \sigma_{24}^2$	
34	2	756.00	378.00	$\sigma_e^2 + 4\ \sigma_{34}^2$	
Residual	9	7522.81	835.87	σ_e^2	
Total	23	17139.79			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.4.--Analysis of Variance for Subject 11

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	3.38	3.38	$\sigma_e^2 + 12\,\sigma_1^2$	
2-Route	1	2501.04	2501.04	$\sigma_e^2 + 12\,\sigma_2^2$	**
3-Perception Model	2	7905.33	3952.67	$\sigma_e^2 + 6\,\sigma_3^2$	***
4-Attack Mode	1	693.37	693.37	$\sigma_e^2 + 12\,\sigma_4^2$	
12	1	900.37	900.37	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	4107.00	2053.50	$\sigma_e^2 + 4\,\sigma_{13}^2$	**
14	1	532.04	532.04	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	533.34	266.67	$\sigma_e^2 + 4\,\sigma_{23}^2$	
24	1	84.38	84.38	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	300.00	150.00	$\sigma_e^2 + 4\,\sigma_{34}^2$	
Residual	9	4068.67	452.07	σ_e^2	
Total	23	21628.91			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.5.--Analysis of Variance for Subject 12

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	170.67	170.67	$\sigma_e^2 + 12\,\sigma_1^2$	
2-Route	1	1.50	1.50	$\sigma_e^2 + 12\,\sigma_2^2$	
3-Perception Model	2	9752.58	4876.29	$\sigma_e^2 + 6\,\sigma_3^2$	**
4-Attack Mode	1	1.50	1.50	$\sigma_e^2 + 12\,\sigma_4^2$	
12	1	2480.67	2480.67	$\sigma_e^2 + 6\,\sigma_{12}^2$	**
13	2	12335.09	6167.54	$\sigma_e^2 + 4\,\sigma_{13}^2$	***
14	1	10.67	10.67	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	391.75	195.87	$\sigma_e^2 + 4\,\sigma_{23}^2$	
24	1	1.50	1.50	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	2784.25	1392.12	$\sigma_e^2 + 4\,\sigma_{34}^2$	
Residual	9	4319.16	479.91	σ_e^2	
Total	23	36557.79			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.6 --Analysis of Variance for Subject 13

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	1	310.08	310.08	$\sigma_e^2 + 6\,\sigma_1^2$	
2-Perception Model	2	1029.17	514.58	$\sigma_e^2 + 4\,\sigma_2^2$	
3-Attack Mode	1	374.08	374.08	$\sigma_e^2 + 6\,\sigma_3^2$	
12	2	155.17	77.58	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	1	1220.08	1220.08	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	510.17	255.08	$\sigma_e^2 + 2\,\sigma_{23}^2$	
Residual	2	820.16	410.08	σ_e^2	
Total	11	4418.91			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.7 --**Analysis of Variance for Subject 6 (Trial Two Only)**

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	1	6.75	6.75	$\sigma_e^2 + 6\,\sigma_1^2$	
2-Perception Model	2	193.50	96.75	$\sigma_e^2 + 4\,\sigma_2^2$	
3-Attack Mode	1	0.08	0.08	$\sigma_e^2 + 6\,\sigma_3^2$	
12	2	393.50	196.75	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	1	30.08	30.08	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	170.17	85.08	$\sigma_e^2 + 2\,\sigma_{23}^2$	
Residual	2	50.17	25.08	σ_e^2	
Total	11	844.25			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F. 8 .--**Analysis of Variance for Subject** 7
(Trial **Two** Only)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	1	52.08	52.08	$\sigma_e^2 + 6\,\sigma_1^2$	
2-Perception Model	2	879.17	439.58	$\sigma_e^2 + 4\,\sigma_2^2$	
3-Attack Mode	1	18.75	18.75	$\sigma_e^2 + 6\,\sigma_3^2$	
12	2	279.17	139.58	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	1	752.08	752.08	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	262.50	131.25	$\sigma_e^2 + 2\,\sigma_{23}^2$	
Residual	2	379.17	189.58	σ_e^2	
Total	11	2622.92			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.9 .--Analysis of Variance for Subject 8 (Trial Two Only)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	1	1064.08	1064.08	$\sigma_e^2 + 6\,\sigma_1^2$	
2-Perception Model	2	1880.67	940.33	$\sigma_e^2 + 4\,\sigma_2^2$	
3-Attack Mode	1	1260.75	1260.75	$\sigma_e^2 + 6\,\sigma_3^2$	
12	2	1248.67	624.33	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	1	1140.75	1140.75	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	134.00	67.00	$\sigma_e^2 + 2\,\sigma_{23}^2$	
Residual	2	482.00	241.00	σ_e^2	
Total	11	7210.90			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.10.--Analysis of Variance for Subject 11
(Trial Two Only)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	1	3201.33	3201.33	$\sigma_e^2 + 6\,\sigma_1^2$	**
2-Perception Model	2	308.17	154.08	$\sigma_e^2 + 4\,\sigma_2^2$	
3-Attack Mode	1	5.33	5.33	$\sigma_e^2 + 6\,\sigma_3^2$	
12	2	88.17	44.08	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	1	705.33	705.33	$\sigma_e^2 + 3\,\sigma_{13}^2$	*
23	2	20.17	10.08	$\sigma_e^2 + 2\,\sigma_{23}^2$	
Residual	2	160.17	80.08	σ_e^2	
Total	11	4488.66			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.11.--Analysis of Variance for Subject 12
(Trial Two Only)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Route	1	1180.08	1180.08	$\sigma_e^2 + 6\,\sigma_1^2$	**
2-Perception Model	2	16750.17	8375.08	$\sigma_e^2 + 4\,\sigma_2^2$	***
3-Attack Mode	1	10.08	10.08	$\sigma_e^2 + 6\,\sigma_3^2$	
12	2	230.17	115.08	$\sigma_e^2 + 2\,\sigma_{12}^2$	
13	1	10.08	10.08	$\sigma_e^2 + 3\,\sigma_{13}^2$	
23	2	50.17	25.08	$\sigma_e^2 + 2\,\sigma_{23}^2$	
Residual	2	50.15	25.08	σ_e^2	
Total	11	18280.89			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.12.--Analysis of Variance for Subject 13 (Trial Two Only)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	5.33	5.33	$\sigma_e^2 + 24\,\sigma_1^2 + 12\,\sigma_{13}^2$	
2-Route	1	1950.75	1950.75	$\sigma_e^2 + 24\,\sigma_2^2 + 12\,\sigma_{23}^2$	
3-Subject	1	3675.00	3675.00	$\sigma_e^2 + 24\,\sigma_3^2$	***
4-Perception Model	2	1107.54	553.77	$\sigma_e^2 + 16\,\sigma_4^2 + 8\,\sigma_{34}^2$	
5-Attack Mode	1	574.08	574.08	$\sigma_e^2 + 24\,\sigma_5^2 + 12\,\sigma_{35}^2$	
12	1	80.08	80.08	$\sigma_e^2 + 12\,\sigma_{12}^2$	
13	1	85.33	85.33	$\sigma_e^2 + 12\,\sigma_{13}^2$	
14	2	744.29	372.15	$\sigma_e^2 + 8\,\sigma_{14}^2$	
15	1	140.08	140.08	$\sigma_e^2 + 12\,\sigma_{15}^2$	
23	1	1752.09	1752.09	$\sigma_e^2 + 12\,\sigma_{23}^2$	**
24	2	529.63	264.81	$\sigma_e^2 + 8\,\sigma_{24}^2$	
25	1	161.33	161.33	$\sigma_e^2 + 12\,\sigma_{25}^2$	
34	2	717.88	358.94	$\sigma_e^2 + 8\,\sigma_{34}^2$	
35	1	444.08	444.08	$\sigma_e^2 + 12\,\sigma_{35}^2$	
45	2	787.79	393.90	$\sigma_e^2 + 8\,\sigma_{45}^2$	
Residual	27	10021.33	371.16	σ_e^2	
Total	47	22776.59			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.13.--Analysis of Variance for Subjects 7 and 11

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1-Block	1	420.08	420.08	$\sigma_e^2 + 24\,\sigma_1^2 + 12\,\sigma_{13}^2$	
2-Route	1	0.08	0.08	$\sigma_e^2 + 24\,\sigma_2^2 + 12\,\sigma_{23}^2$	
3-Subject	1	3300.08	3300.08	$\sigma_e^2 + 24\,\sigma_3^2$	**
4-Perception Model	2	388.79	194.40	$\sigma_e^2 + 16\,\sigma_4^2 + 8\,\sigma_{34}^2$	
5-Attack Mode	1	705.33	705.33	$\sigma_e^2 + 24\,\sigma_5^2 + 12\,\sigma_{35}^2$	
12	1	4107.00	4107.00	$\sigma_e^2 + 12\,\sigma_{12}^2$	***
13	1	533.33	533.33	$\sigma_e^2 + 12\,\sigma_{13}^2$	
14	2	1008.29	504.15	$\sigma_e^2 + 8\,\sigma_{14}^2$	
15	1	396.75	396.75	$\sigma_e^2 + 12\,\sigma_{15}^2$	
23	1	5043.00	5043.00	$\sigma_e^2 + 12\,\sigma_{23}^2$	***
24	2	1738.29	869.15	$\sigma_e^2 + 8\,\sigma_{24}^2$	
25	1	0.08	0.08	$\sigma_e^2 + 12\,\sigma_{25}^2$	
34	2	11245.78	5622.89	$\sigma_e^2 + 8\,\sigma_{34}^2$	***
35	1	114.08	114.08	$\sigma_e^2 + 12\,\sigma_{35}^2$	
45	2	115.79	57.90	$\sigma_e^2 + 8\,\sigma_{45}^2$	
Residual	27	12129.85	449.25	σ_e^2	
Total	47	41246.58			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.14.--Analysis of Variance for Subjects 8 and 12

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1- Route	1	620.17	620.17	$\sigma_e^2 + 12\,\sigma_1^2 + 6\,\sigma_{12}^2$	
2- Subject	1	1320.17	1320.17	$\sigma_e^2 + 12\,\sigma_2^2$	*
3- Perception Model	2	1634.08	817.04	$\sigma_e^2 + 8\,\sigma_3^2 + 4\,\sigma_{23}^2$	
4- Attack Mode	1	640.67	640.67	$\sigma_e^2 + 12\,\sigma_4^2 + 6\,\sigma_{24}^2$	
12	1	450.67	450.67	$\sigma_e^2 + 6\,\sigma_{12}^2$	
13	2	143.58	71.79	$\sigma_e^2 + 4\,\sigma_{13}^2$	
14	1	400.17	400.17	$\sigma_e^2 + 6\,\sigma_{14}^2$	
23	2	440.08	220.04	$\sigma_e^2 + 4\,\sigma_{23}^2$	
24	1	620.17	620.17	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	289.08	144.54	$\sigma_e^2 + 4\,\sigma_{34}^2$	
Residual	9	2816.50	312.94	σ_e^2	
Total	23	9375.31			

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.01$

Figure F.15.--Analysis of Variance for Subjects 7 and 11 (Trial Two Only)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Mean Squares	Significance
1- Route	1	2035.04	2035.04	$\sigma_e^2 + 12\,\sigma_1^2 + 6\,\sigma_{12}^2$	
2- Subject	1	3243.37	3243.37	$\sigma_e^2 + 12\,\sigma_2^2$	***
3- Perception Model	2	74.08	37.04	$\sigma_e^2 + 8\,\sigma_3^2 + 4\,\sigma_{23}^2$	
4- Attack Mode	1	22.04	22.04	$\sigma_e^2 + 12\,\sigma_4^2 + 6\,\sigma_{24}^2$	
12	1	1218.38	1218.38	$\sigma_e^2 + 6\,\sigma_{12}^2$	***
13	2	231.58	115.79	$\sigma_e^2 + 4\,\sigma_{13}^2$	
14	1	1457.04	1457.04	$\sigma_e^2 + 6\,\sigma_{14}^2$	***
23	2	1113.25	556.62	$\sigma_e^2 + 4\,\sigma_{23}^2$	**
24	1	2.04	2.04	$\sigma_e^2 + 6\,\sigma_{24}^2$	
34	2	127.58	63.79	$\sigma_e^2 + 4\,\sigma_{34}^2$	
Residual	9	830.55	92.28	σ_e^2	
Total	23	10354.94			

* Significant at α = 0.10
** Significant at α = 0.05
*** Significant at α = 0.01

Figure F.16.--Analysis of Variance for Subjects 8 and 12 (Trial Two Only)

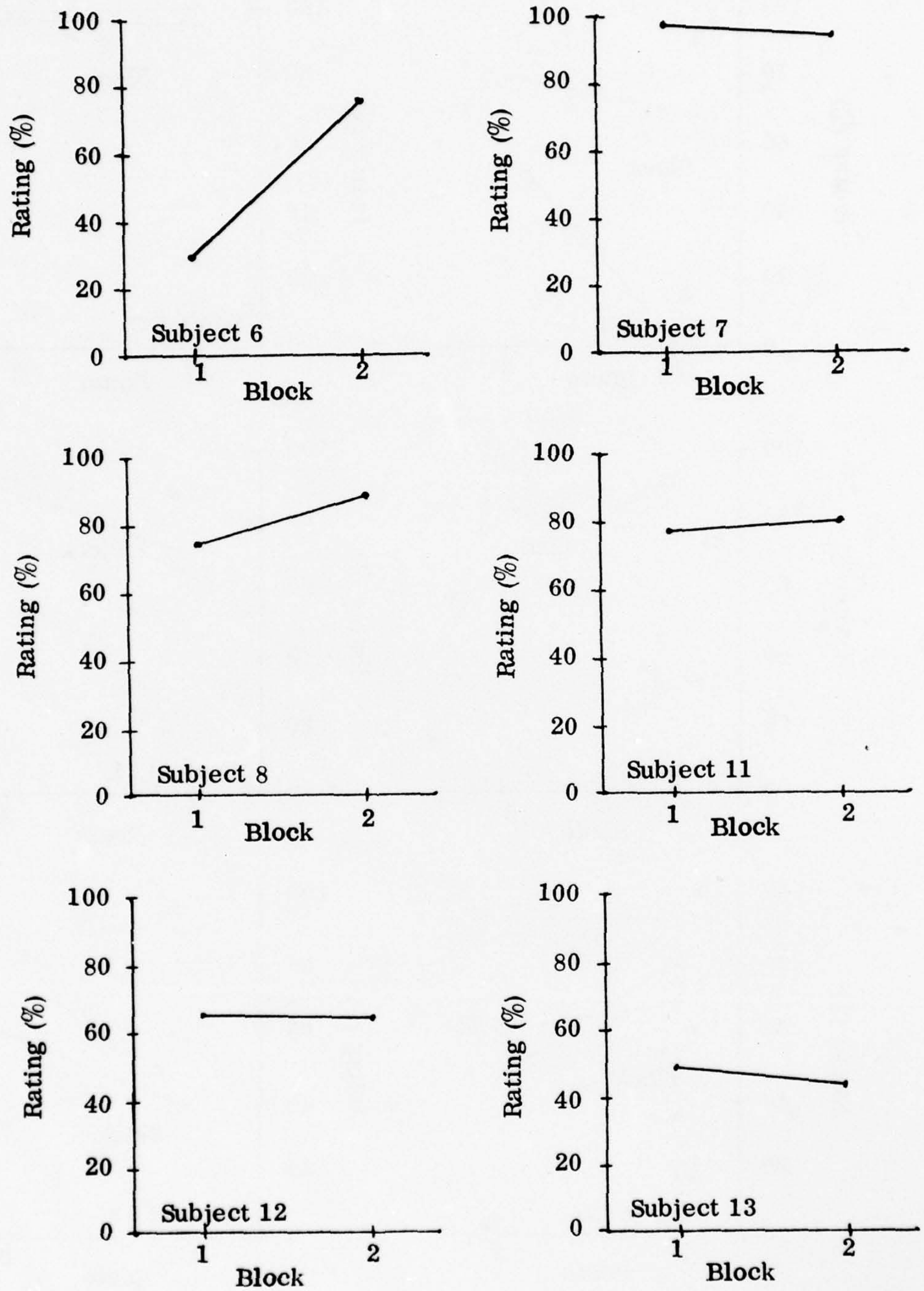


Figure F. 17. --Plot of Block Effect by Subject (Block One-Phase II, Block Two - Trial Two)

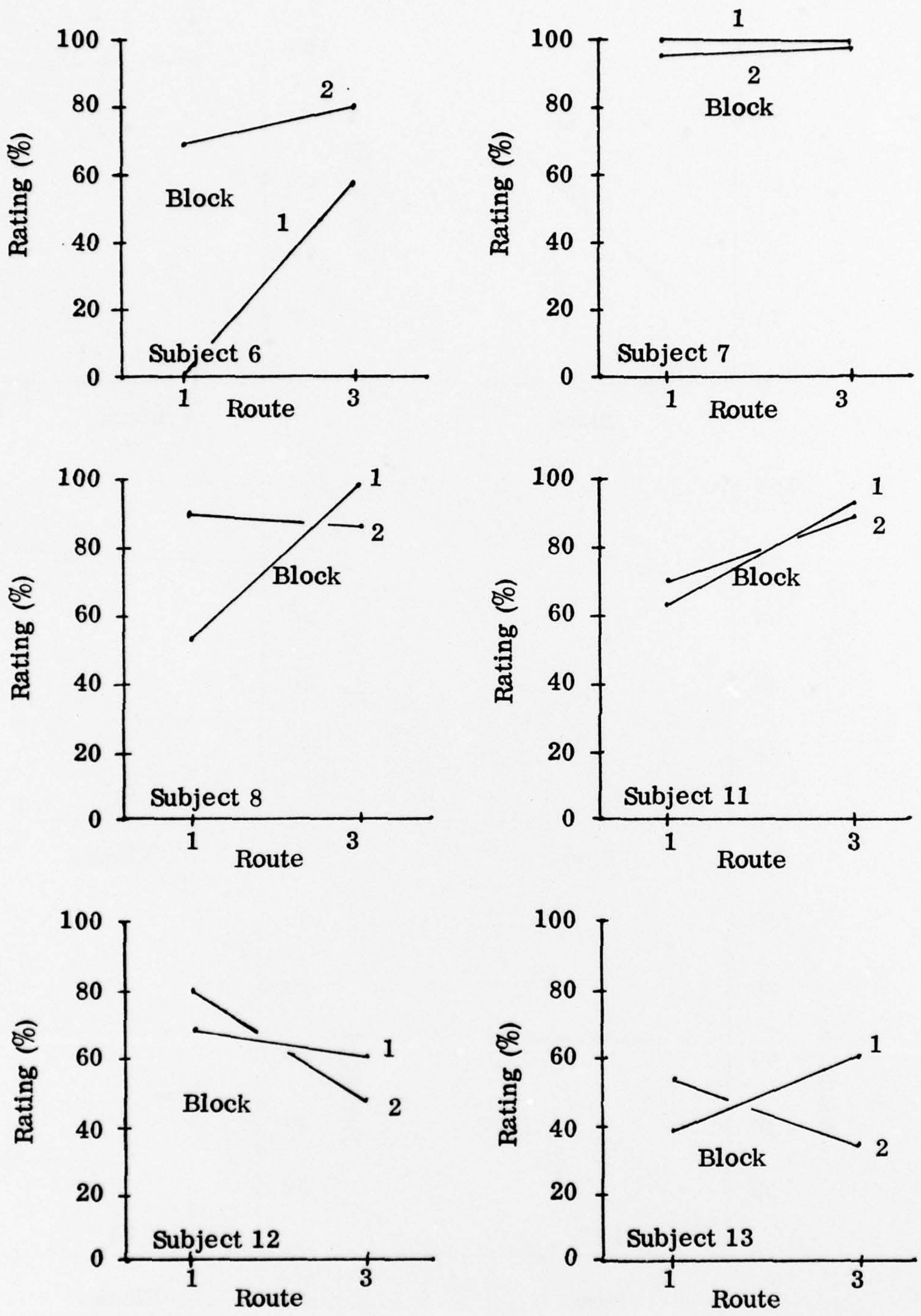


Figure F. 18. --Plot of Route Effect by Block and Subject
(Block One - Phase II, Block Two-Trial Two)

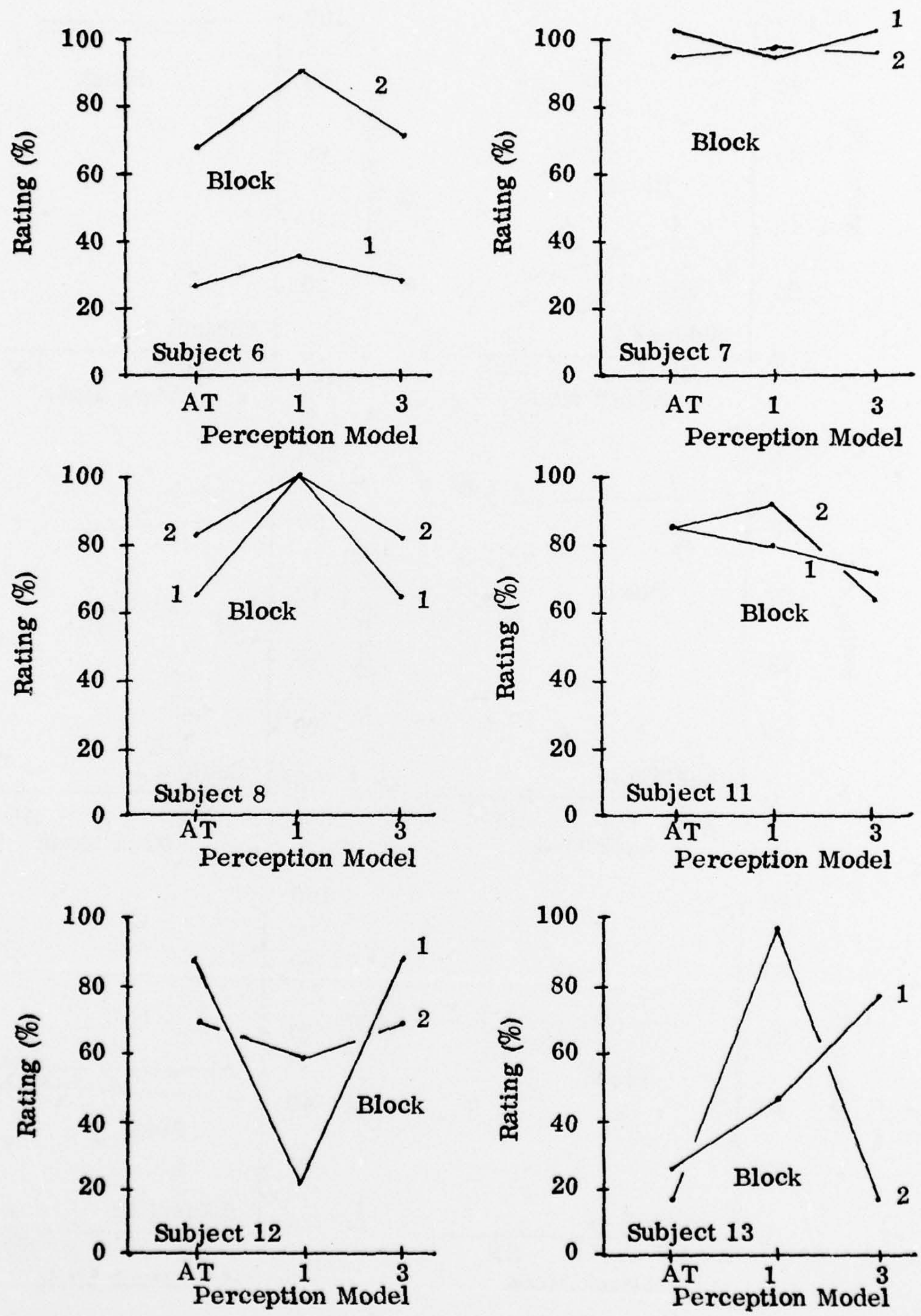


Figure F.19.--Plot of Perception Model Effect by Block and Subject
(Block One - Phase II, Block Two - Trial Two)

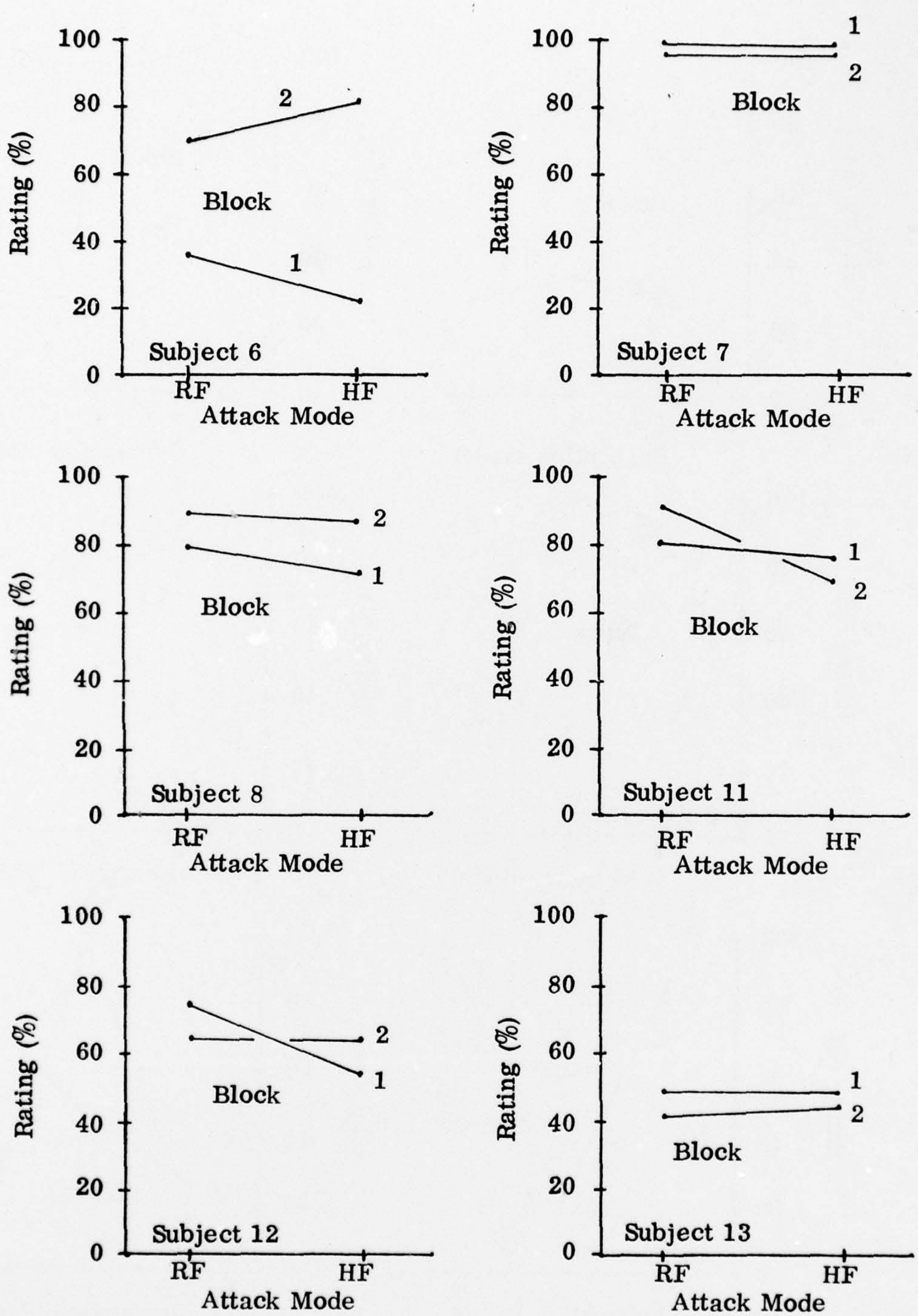


Figure F. 20.--Plot of Attack Mode Effect by Block and Subject
(Block One - Phase II, Block Two - Trial Two)

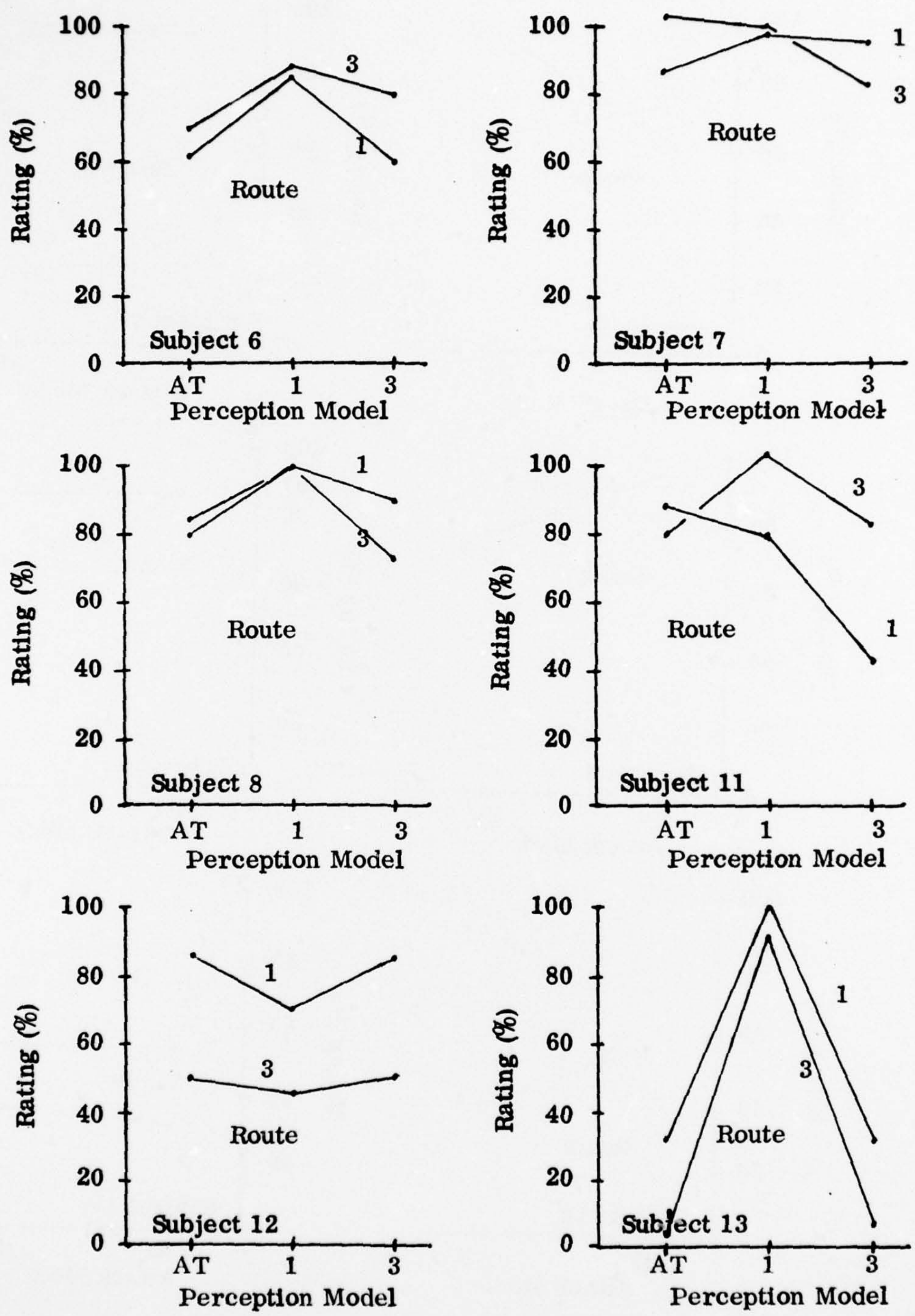


Figure F. 21.--Plot of Perception Model Effect by Route and Subject (Trial Two Only)

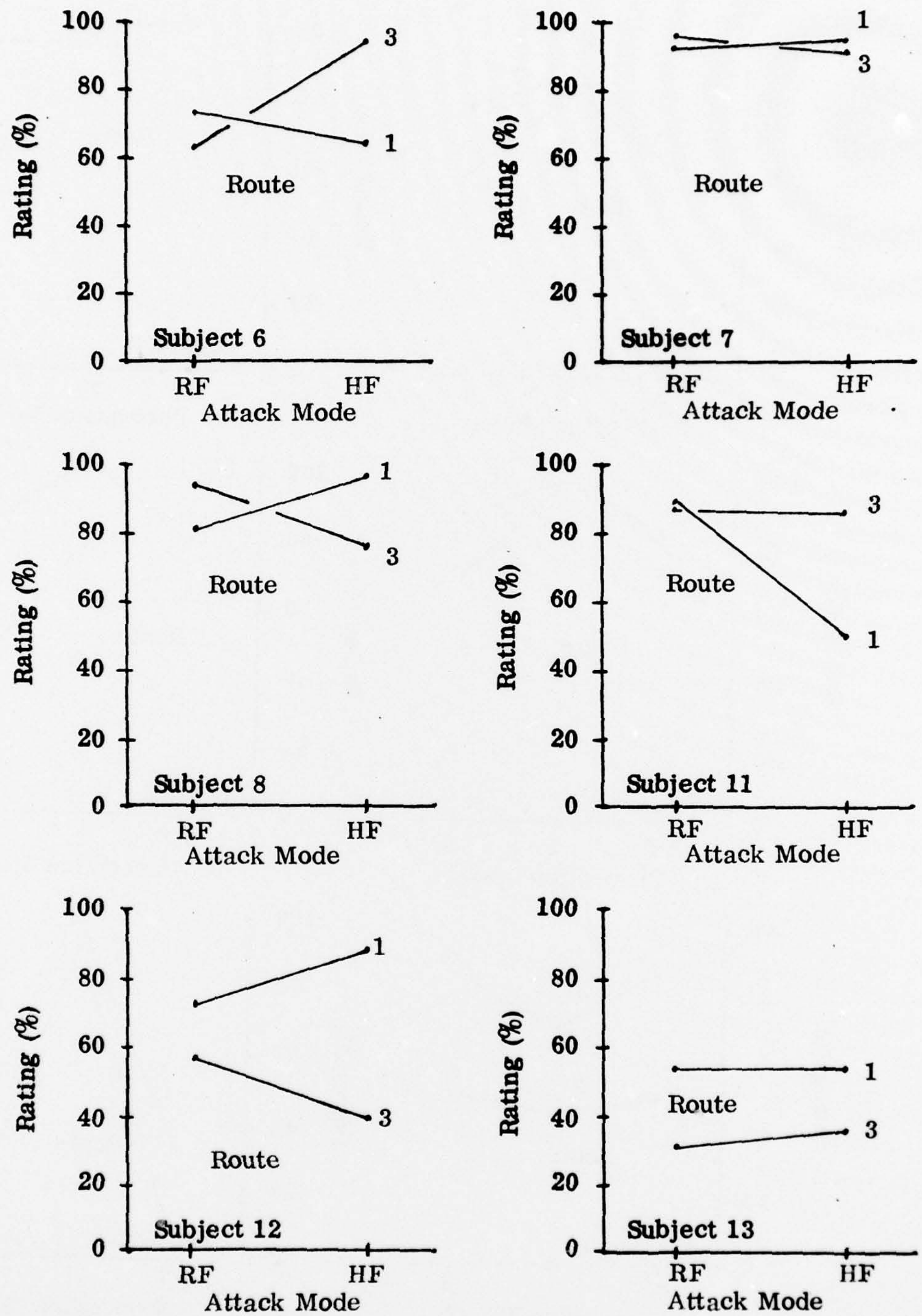


Figure F. 22. --Plot of Attack Mode Effect by Route and Subject (Trial Two Only)

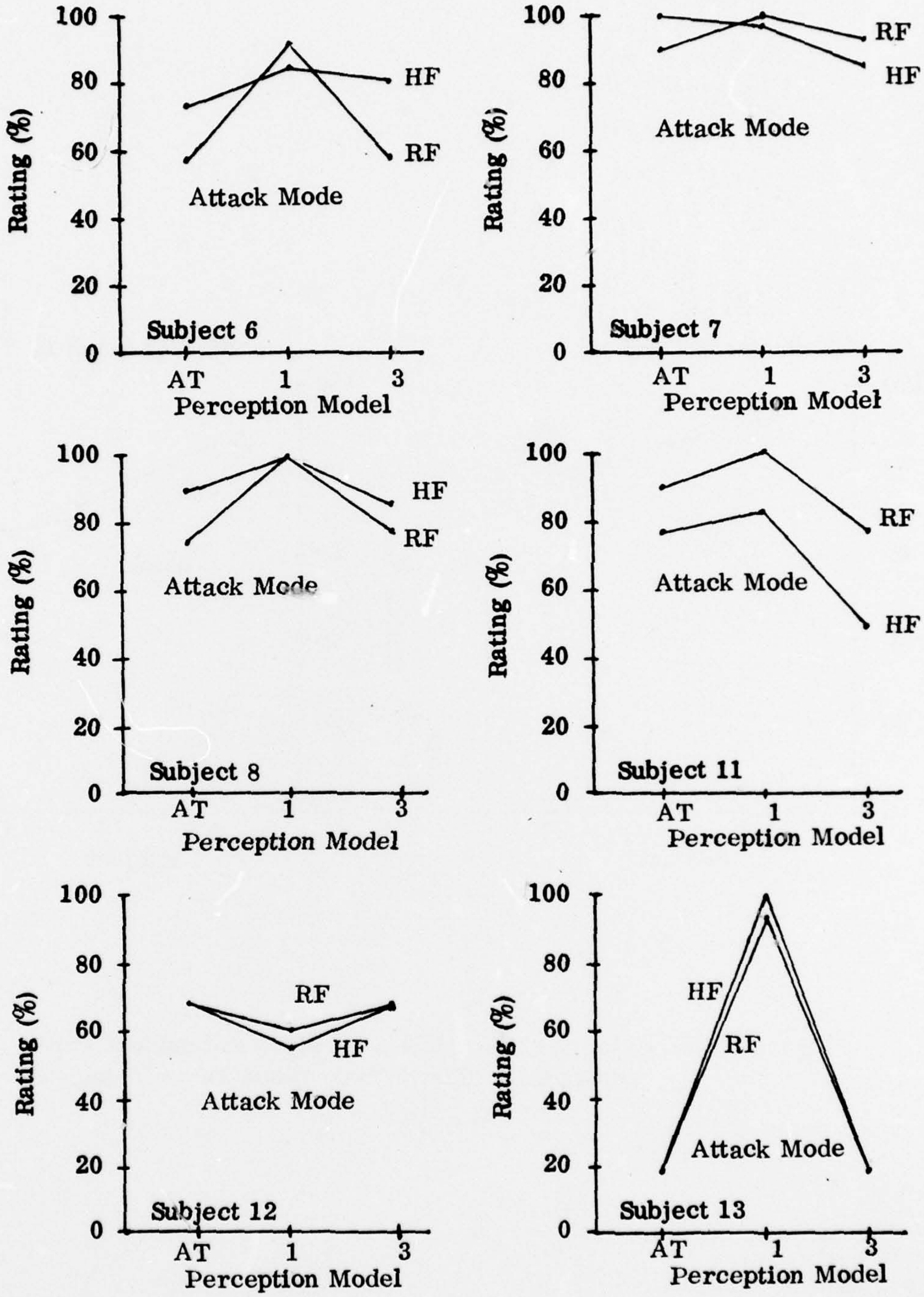


Figure F. 23. --Plot of Perception Model Effect by Attack Mode and Subject (Trial Two Only)

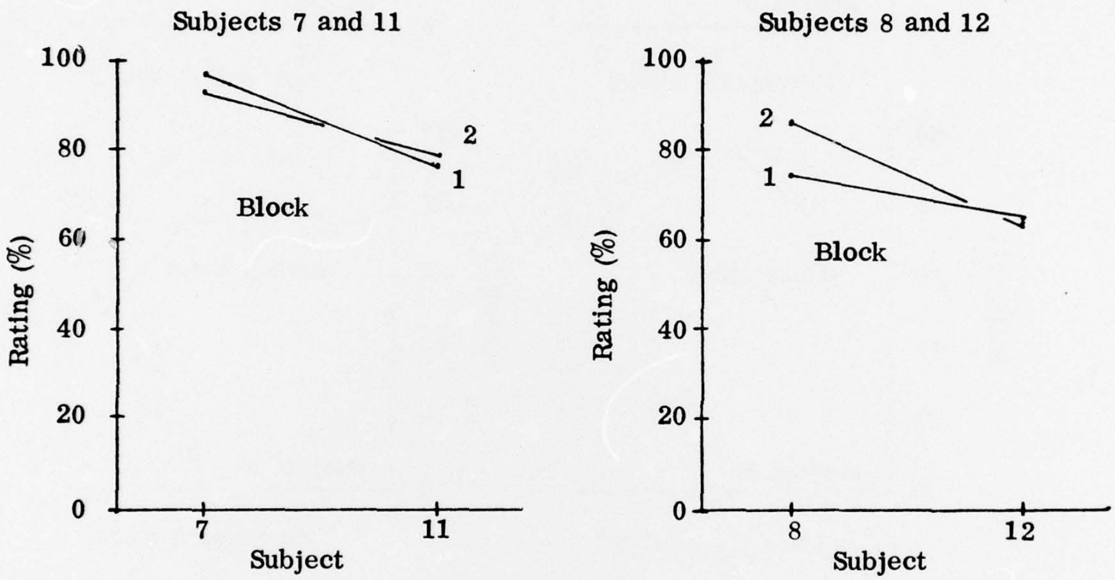


Figure F. 24.--Plot of Subject Effect by Block and Subject Pair (Block One - Phase Two, Block Two - Trial Two)

APPENDIX G

A PRELIMINARY EXPERIMENT

As preparation for the Phase I and Phase II Experiments reported in Chapters 3 and 4, a preliminary experiment was conducted. The purpose of this experiment was to investigate the procedures that were being considered for use during Phase I and Phase II. It was desired that the validity of these procedures be established before they be depended upon to produce results in a production environment.

The subject group used during the preliminary experiment was selected from a group of volunteers who were members of an air cavalry troop of the Ohio Air National Guard stationed at Columbus, Ohio. All subjects had had significant combat experience as gunship pilots in Vietnam.

The portion of the preliminary experiment corresponding to Phase I was conducted at the Ohio National Guard Armory on December 4, 1971. Out of eight subjects selected to participate, three were unable to attend the session at the appointed hour. Consequently, they were dropped from further consideration. Furthermore, of the remaining five subjects, two were required to leave before they had completed even the threat evaluation phase of the experiment. Thus, only three subjects actually completed the entire Phase I Experiment.

During Phase I the procedures used were essentially those described in Chapter 3 and Appendix B. There were two important differences, however. First, no particular effort was made to describe a tactical scenario to which the subjects could relate. It was subsequently discovered that the subjects found it very difficult to render judgments under certain circumstances unless they could

render these judgments in the context of a specific scenario. For example, the subjects could not quote an unexposed travel time that they would find equivalent to a *specified exposed* threat situation unless they were apprised of the tactical scenario in which the decision would be made. A detailed scenario description was incorporated into the Phase I Experiment as a result of this finding.

Second, the preliminary experiment included a procedure that was later dropped from the Phase I session plan. The procedure was designed to determine whether or not the assumption of valuewise independence with respect to exposure to multiple enemy weapons was justified. It was found that without exception the subjects exhibited such behavior. Since it was desired to shorten the Phase I Experiment anyway, it was decided that the procedure could be dropped with little loss in information.

Procedures employed during the portion of the preliminary experiment corresponding to the Phase II Experiment were also similar to those described in Chapter 4 and Appendix D. However, during the preliminary experiment only three alternative routes were prepared for each of the route plans constructed by the subjects. The three alternatives differed from one another only in the threat perception model that was used to measure threat. In each situation the attack mode employed was that selected by the subject himself. Consequently, no data were produced that could be used in measuring an attack mode effect.

Since only three alternatives were to be considered by a subject for each route selection situation, the instructions for ranking and rating the alternatives were different from those employed during the Phase II Experiment. Rather than

rank and rate each alternative relative to his own route plan, each subject was instructed to consider all four routes simultaneously and to rate the best plan at 100. Then the subject was instructed to rate the next best plan on a scale of 0 - 100 using the rules discussed in Chapter 4. The subject was instructed to continue until all route alternatives had been rated. As discussed in Chapter 4 this procedure could not be repeated during Phase II because of the greater number of alternatives to be considered.

A final difference between the preliminary experiment and the Phase II Experiment arose because the National Guard unit to which the subjects belonged met only once a month. Thus, it was necessary to conduct the Phase II Experiment by mail. This turned out to be a very unfortunate circumstance.

On January 17, 1972, each subject was mailed an experimental supply package similar in content to that which was prepared for the subjects participating in the Trial Two Experiment (See Appendix F). However, of the three subjects still participating, only one was prompt in returning his completed experimental package. After repeated phone calls a second subject returned his package in about a month. However, the third subject never did reply, although he promised to on two different occasions. This experience proved very valuable later when it was necessary to conduct the Trial Two Experiment by mail as discussed in Chapter 5. Elaborate precautions were taken to insure that the subjects responded as requested.

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ATTN: AMSAR-SAM/AMCPM-CAWS
Rock Island Arsenal, IL 61202

Commander 2
US Army Aviation Systems Command
ATTN: AMSAV-EVW/AMCPM-AAH
St. Louis, MO 63166

Commander
Command and General Staff School
ATTN: DDOC
Fort Leavenworth, Kansas 66027 | 2

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Commander US Army Logistics Center ATTN: ATCL-M Ft. Knox, KY 40121	1
Commander USA Armor Center ATTN: ATZK-CD-SD Ft. Knox, KY 40121	1
Commandant USA Infantry School ATTN: ATZD-CD-CS Ft. Benning, GA 31905	1
Commandant USA Field Artillery Center and Ft. Sill ATTN: ATSF-CD Ft. Sill, OK 73503	1
Commandant US Army Aviation Center ATTN: ATZQ-D-SGC Ft. Rucker, AL 36362	3
Commandant US Air Defense School ATTN: ATSA-CTD Ft. Bliss, TX 79916	1
Deputy Commander Combined Arms Combat Development Activity USACACDA ATTN: ATCA-CCM-F Ft. Leavenworth, Kansas 66027	5